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Coral Reproduction, Part 2
Analysis of 150 Watt DE Lamps
MaxiJet Utility Pumps
Total Organic Carbon & the Aquarium

photographs by Terry Siegel

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ADVANCED AQUARIST'S ONLINE MAGAZINE

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EDITORIAL

August 2008

By Terry Siegel

Terry discusses this month's issue.

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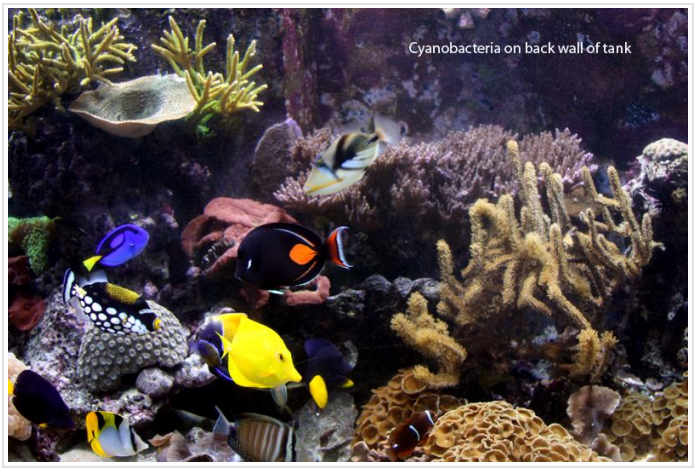
This month *Advanced Aquarist* is pleased to present what, in our judgment, is a very important paper, entitled *Total Organic Carbon (TOC) and the Reef Aquarium: an Initial Survey, Part 1*, Ken S. Feldman and Kelly M. Maers, from the Department of Chemistry, The Pennsylvania State University, University Park, PA 16802.

As most of our readers know the coral reefs of the world are in trouble, with some scientists suggesting that as much as 70% of the planet's coral reefs will die within the next 50 years. Research suggests that the biochemical causes are complex, with human activity playing a significant role, and not surprisingly, the forces causing problems for wild corals are all too similar to those that occur in our captive reefs. For example, aquarists often have to deal with what has been referred to as RTN (rapid tissue necrosis), which often appears suddenly, and with devastating results.

It has been my experience that a reef tank reaches optimum health after only a few months, and then gradually environmental factors appear to be deteriorating. Along with the development of unwanted algae and cyanobacteria, water quality becomes more lagoon-like, and in general our man made reefs are less able to support the healthy variety of sea life that it initially did. Part 1 of this paper, along with part 2, which will appear next month, offers us invaluable insight into organic carbon, both *Dissolved Organic Carbon (DOC), Particulate Organic Carbon (POC),* and what effect they have on water quality.

Man's carbon foot print on planet Earth is of great concern today, and for the reef keeper, it is no less a concern, although without as much global consequence. In some important ways our reef aquaria are microcosms, with the world's oceans the macrocosm.

In this issue too we have another in Sanjay Joshi's testing of reef lighting equipment, and Dana Riddle's beginning study of coral reproduction. Jake Adams in previous issues offered our readers valuable information regarding water motion in reef aquaria, arguing that water motion is even more important than lighting. In this issue Jake provides us with a review of the new Maxi Jet Utility Pumps 1100, 1800 and 3000.



Though my reef animals, both vertebrates and invertebrates are quite healthy I continue to battle cyanobacteria. Because water motion is strong in my reef tank this cyanobacteria is unable to smother my corals, but it remains a nuisance, and an indication that my water quality is not as pristine as what is found in nature.

FEATURE ARTICLE

Coral Reproduction, Part Two: Asexual Reproductive Modes of Captive Corals and Anemones

By Dana Riddle

As we shall see, almost every detail of the captive breeding system must be deliberately engineered to consistently and reliably obtain the desired results.

Published August 2008, Advanced Aquarist's Online Magazine.

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For many advanced aquarists, successfully maintaining an array of coral species in captivity is no longer a true challenge. A few dedicated hobbyists are now searching for the keys in unlocking the mysteries of the ultimate challenge in the reef aquarium hobby - that of closing the life cycles of corals and other invertebrates in captivity, where the offspring of captive invertebrates grow, thrive and reproduce in order to begin the cycle anew.

Just 16 years ago, an article in *Audubon* magazine (Derr, 1992) bashed the marine aquarium hobby over the collection of live rock in Florida waters and (in its view) the dismal rate of survival of captive corals (Quote: *"The big commercial aquariums are not much more successful than the home hobbyist in keeping stony coral alive.*"). Further, Derr chose to ignore scattered reports of coral reproduction in captivity (according to those interviewed for the story). If that article was lop-sided and biased in its reporting, it remains a fact that reports of successful sexual broadcast spawnings of corals resulting in settlement and colonization in aquaria are few and far between.

There are many reports of captive corals reproducing asexually via vegetative means including programmed fragmentation of various sorts, including "dripping" and "popping" and others. Some corals bear live young in a process called "brooding" and this is often seen in the stony coral *Pocillopora damicornis* and the azooxanthellate "sun" corals, *Tubastraea* spp.. Hobbyists can take pride when an animal reproduces in an aquarium - it is a rewarding experience and is a demonstration of the aquarist's skills in creating an artificial environment conducive to long-term maintenance of captive animals. Still, reports of successful recruitment of broadcast spawners are scarce. What are we doing wrong (or right)?

This series of articles will examine factors that can encourage, or inhibit, sexual spawnings of aquarium corals. These include salinity, temperature, proper lighting, the effects of ultraviolet radiation, intentional fragmentation, how the tank's life support system impacts reproduction (and vice versa) and water motion. We'll also examine coral colony size and how it relates to sexual maturity, coral life spans, gonochoric sex ratios, egg size, techniques to artificially fertilize eggs, planula larvae competency, and even how to induce coral spawnings. Post-spawning requirements such as substrate preference, light intensity, water motion, resistance to effects of ultraviolet radiation and temperature will also be discussed.

Before beginning, we should ask why we would want to spawn corals in captivity. At first glance, it seems a lofty and worthwhile goal. We can take comfort that we are, even in a small way, conserving natural reefs. Perhaps it will simply be the challenge that motivates a dedicated hobbyist - the "because it is there" mind set. It is doubtful that there would be much financial reward, even if successfully-bred corals were to be a "limited edition", where high prices are asked, and paid. And this will be the situation until collection and importation of corals is restricted or banned (there are serious attempts by various groups to do so every few years). Commercial ventures located near natural coral reefs and having access to clean seawater, abundant sunlight and spawning corals (where planula larvae can be collected from coral spawn slicks) have a better chance of being financially viable (See Goldman, 2006 & 2007). However, GBRMPA (Great Barrier Reef Marine Park Authority) examined the issue of cost-effectiveness in captive coral breeding and concluded that time frames involved would lessen the appeal to commercial operations.

Fret not, this and following articles will barely touch upon intentional fragmentation which is by far the most common method of propagating corals in captivity. Though difficult to imagine, this technique was cutting-edge technology in the 1990s. It is extremely easy to do and can yield outstanding results with *Acropora*, *Montipora*, *Stylophora* and many other taxa. However, fragmentation does not lend itself to some corals.

The hobbyist consistently successful in providing proper environmental conditions to induce captive coral reproduction will not approach it in a haphazard manner. As we shall see, almost every detail of the captive breeding system must be deliberately engineered to consistently and reliably obtain the desired results. We will begin by examining the current state of captive coral reproduction.

Asexual Reproduction

Asexual reproduction is essentially a cloning of the adult colony. This cloning involves several modes known as parthenogenesis, as well as accidental fragmentation and programmed fragmentation (including vegetative propagation, and phenomena called "dripping", "popping" and "budding").

Some corals are capable of self-fertilization (where a colony or even individual polyps contain male and female sex organs) and this is

sometimes referred to as asexual reproduction. Little information on asexual coral reproduction exists in hobby literature, but several authors have devoted at least a few pages of their works to the examination of this phenomenon in aquaria (see Delbeek and Sprung, 1994 (emphasis on stony corals); Sprung and Delbeek, 1997 (emphasis on soft corals, zoanthids, anemones and gorgonians); Borneman, 2001; and Calfo, 2001).

Parthenogenesis

For our purposes, parthenogenic reproduction involves the development of an unfertilized egg with the potential to mature into a new coral colony. Parthenogenesis is common among some insects but occurs infrequently in some anemones (Bell, 1981), and has been *inferred* to occur in at least one soft coral (*Alcyonium* sp., Hartnoll, 1977; McFadden et al., 2001), a gorgonian (*Plexaura* sp.; Brazeau and Lasker, 1989), and several stony corals (*Pocillopora damicornis* (Permata et al., 2000); *Fungia scutaria* (Krupp, 1983), *Porites lobata* and *Porites lutea* - Fadlallah, 1983). Parthenogenesis is also known to occur in a few reptile and fish species. This process would have advantages when individuals of reproductive size are scarce, but has a major disadvantage in that parthenogenically produced colonies are simply clones (female) and lack genetic diversity.

Figure 1. Unidentified soft coral 'twigs' dropped from the adjacent parent colony. This form of reproduction is sometimes called vegetative reproduction. Photo by the author.

Vegetative Propagation

This term often refers to asexual reproduction by plants but applies to corals as well. It is not uncommon, especially in soft corals and gorgonians, for small but complete colonies to detach from the maternal colony (See Figure 1). Another example of vegetative reproduction is that of stoloniferous growth and detachment (see Figure 2).

Programmed Fragmentation - *Diaseris* spp.

Programmed fragmentation, in the case of *Diaseris* species, is a means of reproduction that differs from accidental fragmentation such as that by storms or surge, and intentional fragmentation by hobbyists. With *Diaseris* spp., programmed fragmentation involves slit formation with associated skeletal dissolution, resulting in small, roughly tear-drop shaped colonies dropping away from the parent colony (See Figure 3 and 4). These daughter colonies eventually grow a new mouth and mature quickly to functional adults. Colley et al., 2000 describe the frequency of this occurrence as 'high rate' on natural reefs.

"Dripping"

Dripping is a term used to describe a slow detachment and separation of viable tissues from an adult coral colony. The separation is in essence a cloning of the adult which allows colonization of an area immediately surrounding the adult. The new colony may, or may not, contain a skeleton.

Figures 8 through 10 show "dripping" of several Caribbean coral taxa. These photographs were taken in a refugium of an aquarium

Figure 2."Runners" called stolons, could eventually detach from the parent colony and become a new soft coral colony. Photo by the author.

maintained by Bill Hoffman of the Smithsonian Marine Station in Fort Pierce, Florida. The photographer (Julian Sprung) relayed his observations of these corals. Sprung noticed the developing offspring tended to be localized and speculates that the causative agent of these "bubbles" might be viral, or perhaps a response to environmental conditions such as high light intensity or ultraviolet radiation. In any case, the corals are not bleached and seem to suffer no permanent damage.

Figures 11 and 12 are of "satellite" or "daughter" colonies of the stony coral *Goniopora*. These corals are also known to reproduce sexually, with broadcasting of gametes from separately-sexed (gonochoric) parent colonies. At least one *Goniopora* species is known to be a brooder.

Figure 3. Daughter colonies of Diaseris. Aquarist Larry Jackson reports he has given away about 150 colonies that were asexually produced within his aquaria. Photo courtesy of Larry Jackson.

Figure 4. The underside of an adult Diaseris showing its developing fragmentation lines. Portions of the colony will soon break away. Photo courtesy Larry Jackson.

"Popping"

"Popping", as described by Kramarsky-Winter (1997) is another asexual reproductive mode where new colonies arise from a maternal colony (or sometimes the remains of an adult colony). These new colonies eventually break away. This reproductive mode is seen in stony corals (including genera *Fungia, Trachyphyllia, Turbinaria, Euphyllia, Psammocora* and others) and soft corals.

Goemans (2000) reported similar "popping" of a captive coral identified as *Turbinaria peltata* and a soft coral (*Sarcophyton elegans*, commonly called Yellow Fiji leather coral). Calfo (2001) also reports similar "popping" of a *Turbinaria* specimen.

"Brooding" Corals

Brooding is the act of retaining fertilized eggs either internally or upon a coral"s surface. This reproductive technique bears young (planula larvae) of relatively large size, though in fewer numbers than broadcast spawners. The advantage of advanced development upon release from the parent colony increases chances of survival.

Figure 5. A "dripping" Anchor coral (Euphyllia ancora). From an aquarium maintained by Gary Moss.

There are at least two brooding corals that routinely reproduce in aquaria, and most reports seem to include the stony coral *Pocillopora damicornis* and the "sun" coral (*Tubastraea* species).

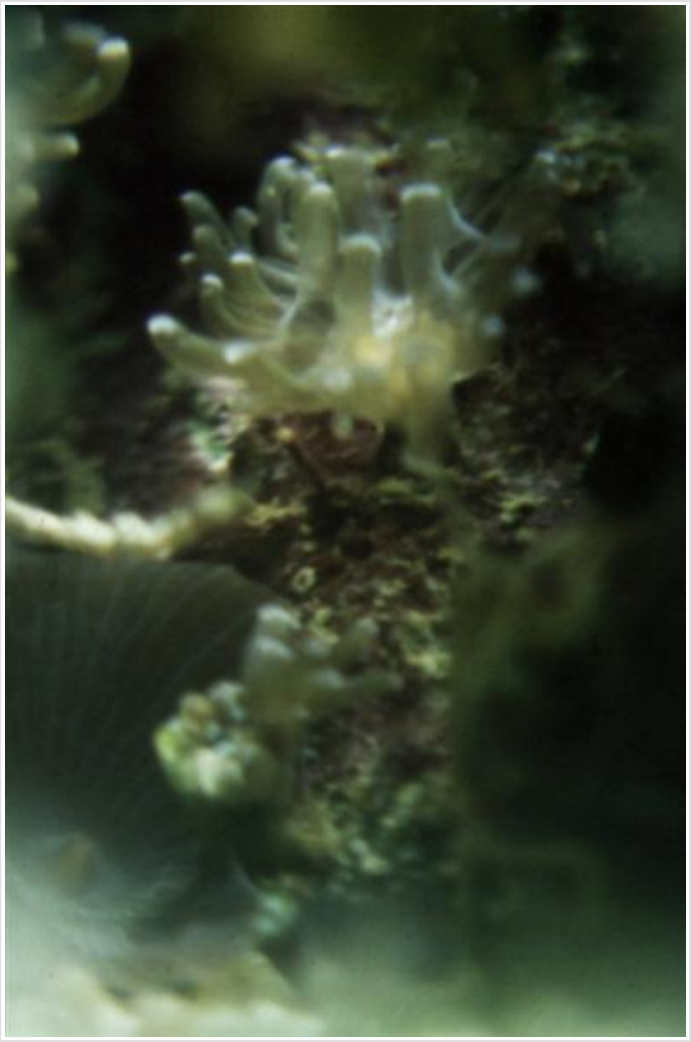

Figure 6. Euphyllia clones that dripped from the parent colony have settled in an aquarium of Gary Moss.

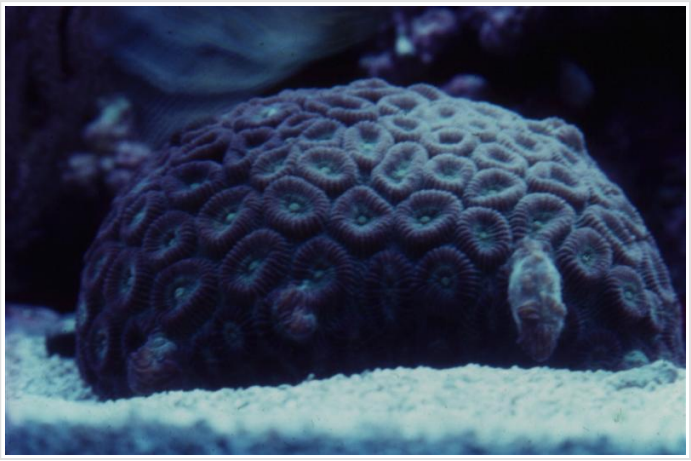

Figure 7. Offspring "dripping" from a stony coral (Favia?). From an aquarium maintained by Steve Poleo, The Aquarium, Tempe, Arizona.

Reproduction by these corals requires little effort on the part of the hobbyist (other than routine husbandry chores) and it is possible for many larvae to settle and attach to substrata.

Anemones

Anemones reproduce sexually and asexually. All too many hobbyists are familiar with asexual pedal budding (or pedal laceration) of "pest" anemones such as *Aiptasia* and *Boloceroides*. On the other hand, some desirable species also reproduce asexually in aquaria through means known as longitudinal fission ("splitting down the middle"), budding, and possible cloning via parthenogenesis (Walker and Bull, 1983).

Acknowledgements

The author is indebted to those answering a request for coral reproduction photographs, as well as those who allowed me into their businesses and homes across the country and kindly granted

Figure 8. Dendrogyra cylindrus forming tissue bubbles that will eventually develop a skeleton and drop off. Photographed in a refugium at the Smithsonian Marine Station, Ft. Pierce, Florida. Photo courtesy of Julian Sprung.

Figure 9. Montastrea cavernosa adjacent to the Dendrogyra in the same tank, forming the same type of tissue bubbles. Note advanced development. Photo courtesy of Julian Sprung.

permission to document their animals' activities. For this installment, these persons are:

Joe Ranney (then of Cleveland Ohio); Eric Amadio of Phoenix, Arizona; Steve Poleo, Tempe, Arizona; Rich Durso; Pete Mohan then of Sea World Ohio; Steven Pro, Pittsburgh, Pennsylvania; Julian Sprung of Two Little Fishies, Coconut Grove, Florida; Larry Jackson, San Angelo, Texas; Steve Ruddy of Coral Reef Ecosystems, Guerneville, California; Bob Lemke of Canton, Georgia; Gary Moss of Baltimore, Maryland; Walter Bobe, Canton, Georgia; and The Fish Store and More, Atlanta, Georgia.

Invariably, I have misplaced notes of some photographs, or the markings on slides have become illegible over the years. To those individuals, I apologize but salute you for your dedication.

Several factors influenced my decision to dedicate the time and effort to write this series of articles. A major consideration was preservation of some of the photographs and transparencies I have accumulated over the years. Some photographs were stored in a shoebox while some slides were showing signs of deterioration in the warm, humid climate of Hawaii. Many of the photographs in this article were taken when consumer level digital photography was unknown, when we made do with cameras with an extremely limited number of possible photographs. We did not have the luxury of instant photograph review then, which resulted in many pictures of poor and unusable quality. Some of my photographs are testaments to the tribulations of silver-based photography. However, I felt it better to share them than have them degrade and become lost forever.

A complete reference list will be presented at the close of this series.

Questions? Comments? Reach me at: RiddleLabs@aol.com

Figure 10. Mycetophyllia aliciae (adjacent to the corals in Figures 8 and 9) has some tissue buds forming along the side facing them. Note settled daughter colony of M. cavernosa (out of focus) between the corals. Photo courtesy of Julian Sprung.

Figure 11. This Goniopora stony coral is producing at least two "daughter" or "satellite" offspring (whiles others, already detached, are to left and behind). Photo courtesy Larry Jackson.

Figure 12. A Goniopora daughter colony isolated in a spawning basket. From one of the author"s aquaria in the early 1990"s.

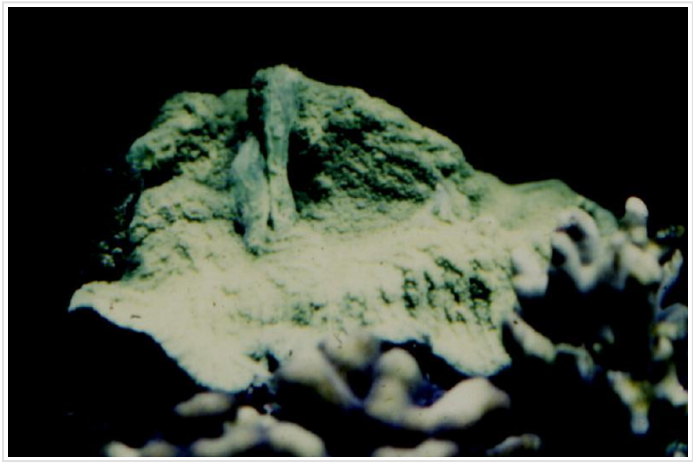

Figure 13. An unidentified stony coral dripping at least two new colonies. Photo by the author.

Figure 14. A stony coral (possibly Caulastrea) dripping a clonal colony. Photo by the author.

Figure 15. Sub-adult Elegance corals (Catalaphyllia jardineri; at lower right) produced asexually in an aquarium maintained by aquarist Richard Durso. Photo courtesy of R. Durso.

Figure 16. Lobophyllia sp. forming a bud on its surface in the "big aquarium" - the Pacific Ocean. Photographed in the Solomon Islands by Julian Sprung.

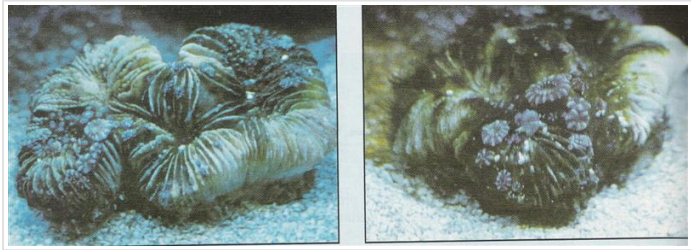

Figure 17. Small colonies "pop" from the remains of an adult Trachyphyllia colony. Photos courtesy Steven Pro.

Figure 18. These mushroom-shaped colonies are "popping" from a Turbinaria reniformiscoral. There are at least 8 of them. Photo by the author.

Figure 19. Many growths are popping above the prominent "twig" on this Turbinaria specimen. Photo courtesy Julian Sprung.

Figure 20. A Turbinaria (peltata?) grows an offspring. Photo courtesy Julian Sprung.

Figure 21. A Euphyllia ancora (Anchor coral) producing a twig-like growth. This will eventually break off and possibly produce a new colony. Courtesy Gary Moss.

Figure 22. Coral "twigs" pop from this adult coral (possibly Psammocora). Photo by the author.

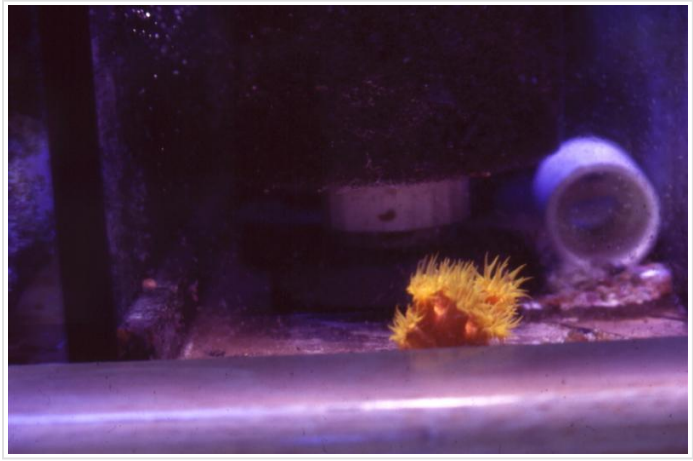

Figure 23. This Tubastraea specimen settled in the overflow of a reef tank where it is exposed to turbulent water motion - and food. Photo by the author.

Figure 24. Another settled Tubastraea, again in an aquarium overflow. Photo by the author.

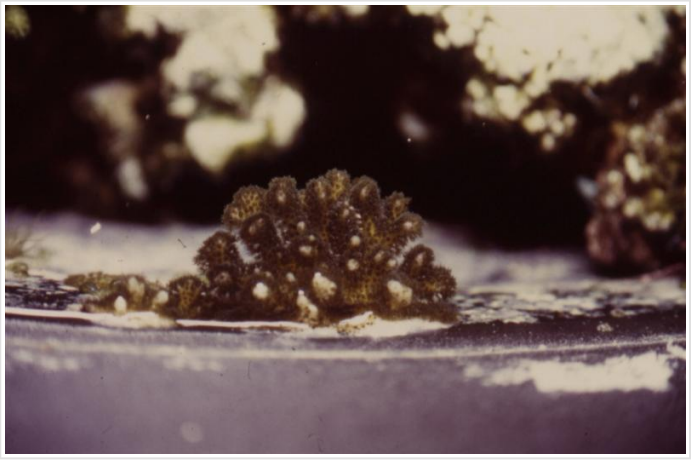

Figure 25. This Pocillopora damicornis has settled on the back wall of an aquarium at Sea World Ohio. Photo by the author.

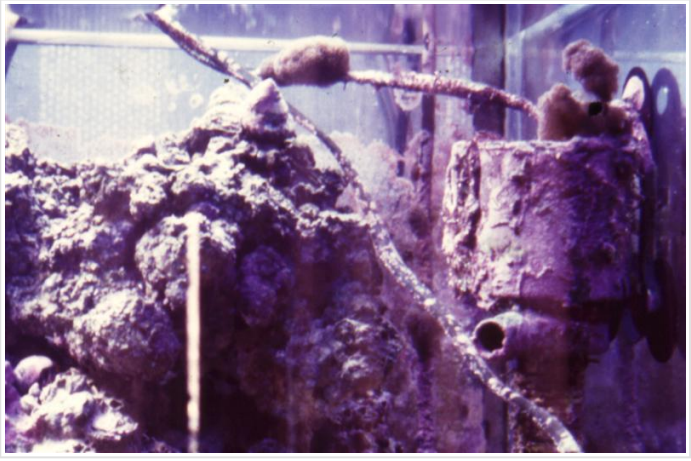

Figure 26. These three Pocillopora damicornis specimens could have been brooded by the simultaneous hermaphroditic parent colony. For reasons unknown, the planula larvae preferred to settle on the powerhead and its electrical cord. From an aquarium of Joe Ranney; photo by the author.

Figure 27. Baskets of young Bubble-tipped anemones are growing out in the aquarium of Bob Lemke. Photo courtesy Bob Lemke.

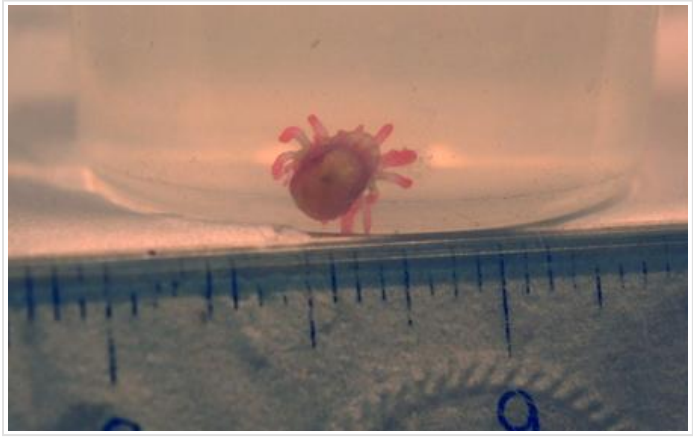

Figure 28. Anemones reproduce sexually as well, as this bubble-tip anemone is believed to have been. Photo courtesy Steve Ruddy.

FEATURE ARTICLE

Spectral Analysis of 150 Watt DE Lamps: Giesmann, Icecap, Iwasaki and Elos

By Sanjay Joshi

Sanjay continues his analysis of the 150 Watt DE Lamps.

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Link to original article: http://www.advancedaquarist.com/2008/8/aafeature2

This article reviews the last of the 150W double ended metal halide lamps tested for their performance and spectral output. Table 1, provides a complete listing of the lamps and ballast combinations test. Included in the tests in the new electronic ballast, sent to me by Current USA. The Iwasaki Kr85 is often sold listed as 50000K lamp. Double ended lams are recommended to be used in enclosed fixtures with a glass shield. Hence these lamps were tested with and without a glass shield. The Icecap lamps represent the new series of lamps.

Table 1: List of lamps and ballasts tested

150W DE Lamps	150W Ballasts
ELOS 150W 10000K PLUS	HQI (M81) Icecap Electronic Aromat Electronic Current USA Electronic
GIESMANN 150W MARINE	
GIESMANN 150W DE CORAL	
GIESMANN 150W DE BLUE	
IWASAKI Kr85 150W DE	
ICECAP 150W 10000K	
ICECAP 150W 14000K	
ICECAP 150W 20000K	

Comparison of Lamp Performance Under Different Ballasts

This section presents the results of testing the different lamps using different ballasts. For each lamp tested different ballasts were used to fire the lamp and data is presented.

ELOS 150W 10000K PLUS

Table 2: ELOS 150W 10000K PLUS

Ballast	Shielded	Power	Voltage	Current	PPFD	CCT	Efficiency
HQI (M81)	N	208	122.8	1.82	76.5	8678	0.36779
HQI (M81)	Y	208	122.8	1.82	61.5	7840	0.29567
Icecap	Y	158	123	1.37	47.5	8198	0.30063
Icecap	N	158	123	1.37	60.2	8869	0.38101
Aromat	N	163	122.9	1.42	61.8	9019	0.37914
Aromat	Y	163	122.9	1.42	49.2	8116	0.30184
Current USA	Y	172	122.6	1.48	50.5	8092	0.29360
Current USA	N	172	122.6	1.48	62.8	8819	0.36512

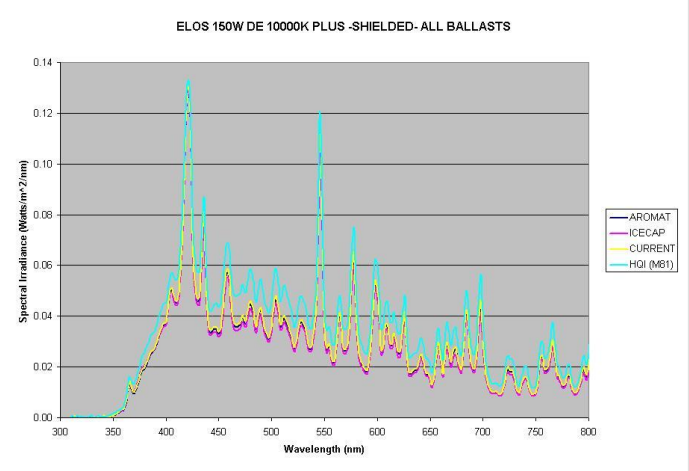

Figure 1: Spectral Plot of the Elos 150W DE Lamp with the different ballasts (Shielded)

Giesmann 150W DE Marine

Table 3: Giesmann 150W DE Marine

Ballast	Shielded	Power	Voltage	Current	PPFD	CCT	Efficiency
Current USA	N	164	122.4	1.42	60	8251	0.36585
Current USA	Y	164	122.4	1.42	48.1	7550	0.29329
Aromat	Y	163	122.6	1.42	48.1	7692	0.29509
Aromat	N	163	122.6	1.42	60.3	8275	0.36994
Icecap	N	158	122.8	1.37	58.4	8251	0.36962
Icecap	Y	158	122.8	1.37	47.1	7465	0.29810
HQI (M81)	Y	203	122.2	1.79	55.9	7500	0.27537
HQI (M81)	N	203	122.2	1.79	76.1	8640	0.37488

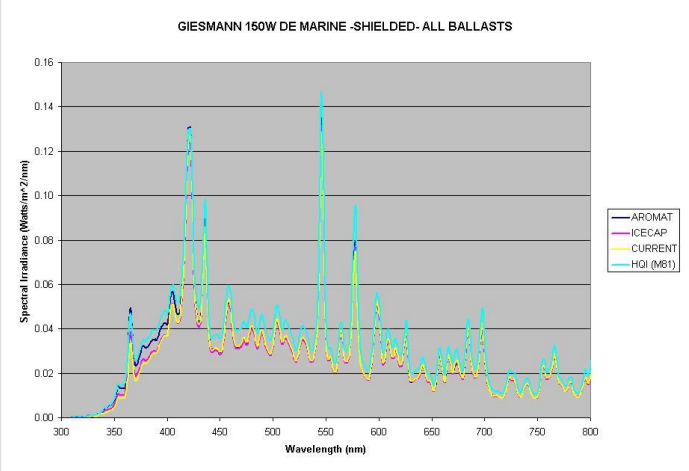

Figure 2: Spectral Plot of the Giesmann 150W DE Marine Lamp with the different ballasts (shielded)

Giesmann 150W DE Coral

Table 4: Giesmann 150W DE Coral

Ballast	Shielded	Power	Voltage	Current	PPFD	CCT	Efficiency
HQI (M81)	N	208	122.9	1.82	62.8	8930	0.30192
HQI (M81)	Y	208	122.9	1.82	50.6	8113	0.24327
Icecap	Y	158	122.3	1.37	39.8	8417	0.25190
Icecap	N	158	122.3	1.37	50.2	9035	0.31772
Aromat	N	163	122.4	1.43	50.9	8972	0.31227
Aromat	Y	163	122.4	1.43	41.5	8134	0.25460
Current USA	Y	173	121.6	1.5	43.9	8112	0.25376
Current USA	N	173	121.6	1.5	54.3	8832	0.31387

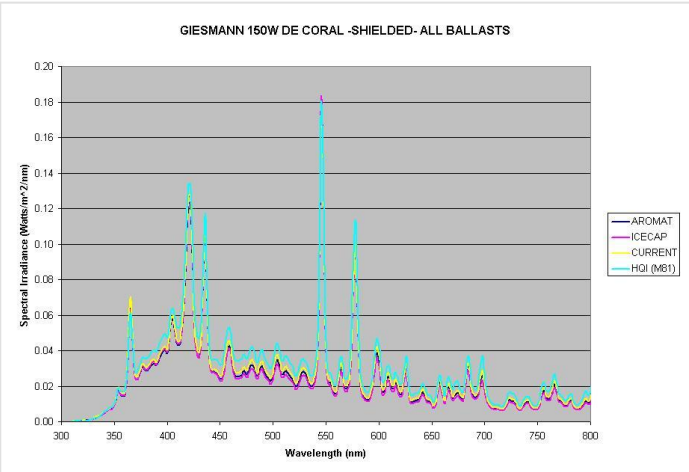

Figure 3: Spectral Plot of the Giesmann 150W DE Coral Lamp with the different ballasts (shielded)

Giesmann 150W DE Blue

Table 5: Giesmann 150W DE Blue

Ballast	Shielded	Power	Voltage	Current	PPFD	CCT	Efficiency
Current USA	N	153	122.2	1.34	22.1		0.14444
Current USA	Y	153	122.2	1.34	17.5		0.11438
Aromat	Y	162	121.2	1.43	19		0.11728
Aromat	N	162	121.2	1.43	24		0.14815
Icecap	N	158	123.3	1.36	24.1		0.15253
Icecap	Y	158	123.3	1.36	18.9		0.11962
HQI (M81)	Y	191	121.8	1.71	20.5		0.10733
HQI (M81)	N	191	121.8	1.71	25.9		0.13560

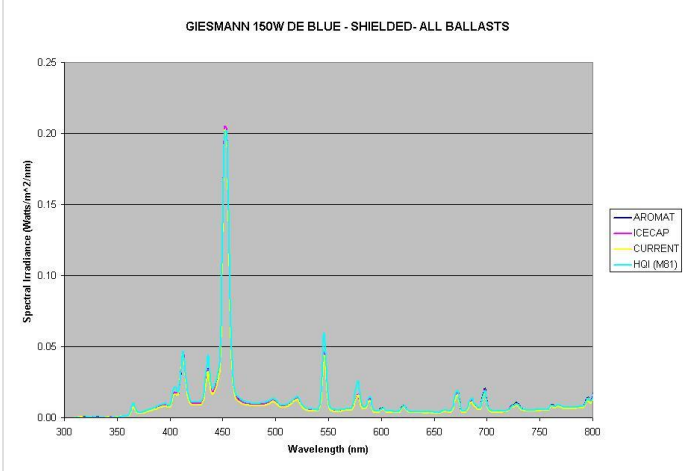

Figure 4: Spectral Plot of Giesmann 150W DE Coral Lamp with the different ballasts (shielded)

Iwasaki Kr85 150W DE

Table 6: Iwasaki Kr85 150W DE

Ballast	Shielded	Power	Voltage	Current	PPFD	CCT	Efficiency
Current USA	N	153	122.2	1.34	22.1	na	0.14444
Current USA	Y	153	122.2	1.34	17.5	na	0.11438
Aromat	Y	162	121.2	1.43	19	na	0.11728
Aromat	N	162	121.2	1.43	24	na	0.14815
Icecap	N	158	123.3	1.36	24.1	na	0.15253
Icecap	Y	158	123.3	1.36	18.9	na	0.11962
HQI (M81)	Y	191	121.8	1.71	20.5	na	0.10733
HQI (M81)	N	191	121.8	1.71	25.9	na	0.13560

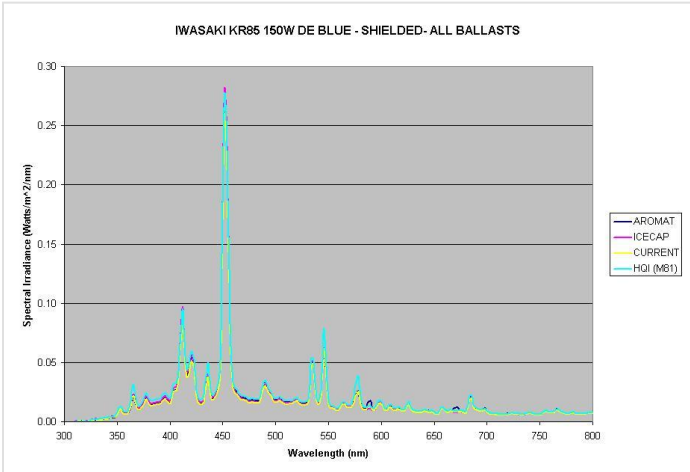

Figure 5: Spectral Plot of Iwasaki Kr85 150W DE Lamp with the different ballasts (shielded)

ICECAP 150W DE 10000K

Table 7: Icecap 150W DE 10000K

Ballast	Shielded	Power	Voltage	Current	PPFD	CCT	Efficiency
Current	N	165	122.5	1.44	69.2	5819	0.41939
Current	Y	165	122.5	1.44	56.3	5624	0.34121
Aromat	Y	163	122.7	1.42	55.6	5765	0.34110
Aromat	N	163	122.7	1.42	69.7	5904	0.42761
Icecap	N	158	122.4	1.37	67.5	5949	0.42722
Icecap	Y	158	122.4	1.37	55.2	4677	0.34937
HQI - M81	Y	198	122.9	1.75	64.9	5679	0.32778
HQI - M81	N	198	122.9	1.75	80.3	6033	0.40556

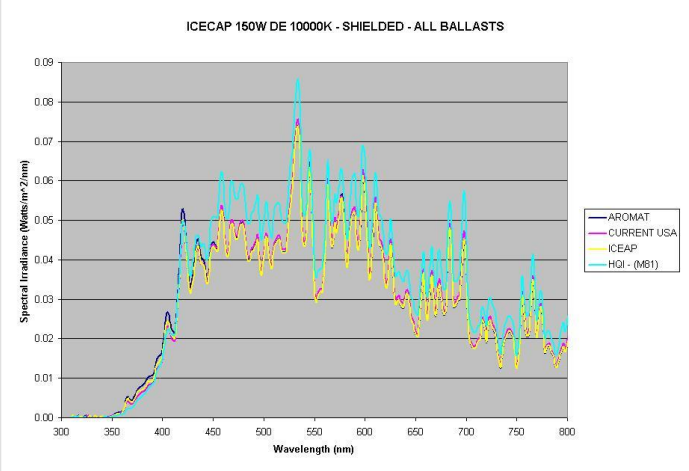

Figure 6: Spectral Plot of Icecap 150W DE 10000K Lamp with the different ballasts (shielded)

ICECAP 150W DE 14000K

Table 8: Icecap 150W DE 14000K

Ballast	Shielded	Power	Voltage	Current	PPFD	CCT	Efficiency
HQI - M81	N	203	122.6	1.79	86.7	6415	0.42709
HQI - M81	Y	204	122.6	1.79	69.6	6025	0.34118
Icecap	Y	158	123	1.36	56.4	5943	0.35696
Icecap	N	158	123	1.36	69.8	6158	0.44177
Aromat	N	163	122.4	1.42	72.2	6217	0.44294
Aromat	Y	163	122.4	1.42	58.9	5931	0.36135
Current	Y	172	122.5	1.48	60.7	5919	0.35291
Current	N	172	122.5	1.48	74.7	6036	0.43430

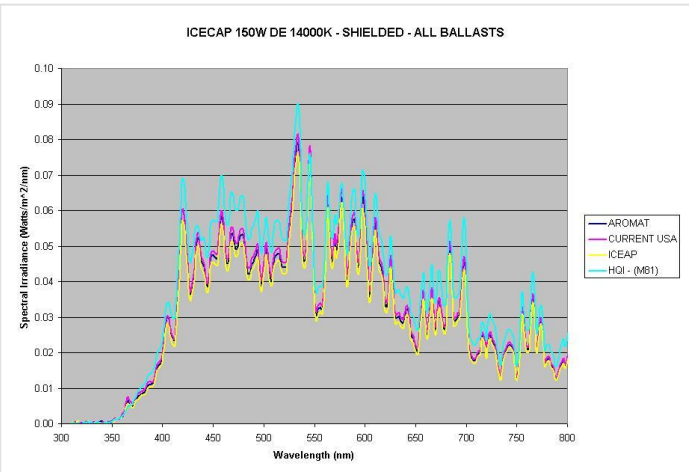

Figure 7: Spectral Plot of Icecap 150W DE 14000K Lamp with the different ballasts (shielded)

ICECAP 150W DE 20000K

Table 9: Icecap 150W DE 20000K

Ballast	Shielded	Power	Voltage	Current	PPFD	CCT	Efficiency
Current	N	158	123.1	1.38	27.2	45956	0.17215
Current	Y	158	123.1	1.38	21.6	na	0.13671
Aromat	Y	161	122.6	1.41	21.8	27578	0.13540
Aromat	N	161	122.6	1.41	26.9	53269	0.16708
Icecap	N	158	122.6	1.38	27.6	na	0.17468
Icecap	Y	158	122.6	1.38	22.2	35847	0.14051
HQI - M81	Y	184	122.5	1.65	22.8	37148	0.12391
HQI - M81	N	184	122.5	1.65	28.6	58681	0.15543

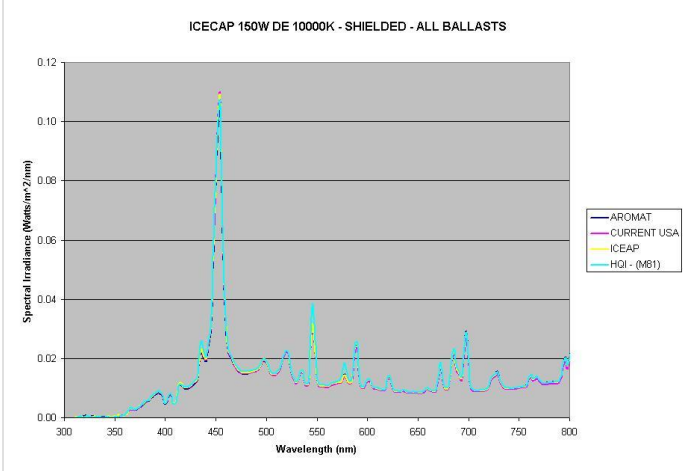

Figure 8: Spectral Plot of Icecap 150W DE 20000K Lamp with the different ballasts (shielded)

DISCUSSION AND CONCLUSIONS

Figures 7 and 8, and Tables 10,11 and 12 compare the Photosynthetic Photon Flux Density (PPFD) and Correlated Color Temperature (CCT) of the unshielded lamps tested here against all the 150W DE metal halide lamps tested. The Elos 10000K plus and Giesmann Marine are very similar in output and CCT. The Icecap 10000K lamps have output comparable to the middle range lamps, and generally have higher output than the Giesmann and Elos lamps on comparable ballasts. However, the CCT for the Icecap lamps is lower than the Elos and Giesmann lamps. In the 14000K category, the was only one prior lamp to compare against - the Aquaconnect 14000K. Both the Icecap and Giesmann lamps have higher PPFD, with the Icecap being the highest. However, the high output is at the cost of much lower CCT, in the 6000K range, making these lamps appear more yellowish. In the 20000K category, both the Giesmann and Icecap come out in the low end of PPFD for the 20000K lamps. The Icecap lamp had a PPFD in the 45000K-58000K range indicating that it may be less blue as compared to the other "20000K" rated lamps which have a CCT that cannot be determined due to the predominance of blue. The Iwasaki Kr85 lamp is usually sold in the aquarium hobby as a 50000K lamp. The spectral plot of this lamp indicates that it will appear quite blue, and it differs from the Icecap and Giesmann Blue lamp since it has extra output in the actinic range (420 nm). As for the PPFD output, its is quite low and would place it in the bottom of all the 20000K lamps tested. The Current USA electronic ballast is similar in performance to the other electronic ballasts.

Table 9: Icecap 150W DE 20000K

	Lamp Name	Ballast Name	PPFD	CCT	Power	Volts	Amps	EFF
1	Sylvania Aqua Arc 150W 10000K DE 1	LampsNow 150W /175W Electronic	95	8153	178	120	1.68	0.5337
2	HIT(BLV) 150W 10000K DE 1	PFO 150W HQI (M81)	83	9128	228	122	1.89	0.364
3	Icecap 150W 10000K DE 1 (new)	PFO 150W HQI (M81)	80	6033	198	122	1.75	0.4056
4	Aqualine Buschke 150W 10000K DE 1	LampsNow 150W /175W Electronic	79	12871	175	119	1.72	0.4514
5	XDE 150W 10000K DE 1	PFO 150W HQI (M81)	77	9445	202	122	1.75	0.3812
6	Icecap 150W 10000K DE 1	PFO 150W HQI (M81)	77	9117	212	120	1.89	0.3632
7	Sylvania Aqua Arc 150W 10000K DE 1	PFO 150W HQI (M81)	77	7844	196	121	1.77	0.3929
8	Giesemann 150W 10000K DE 1	PFO 150W HQI (M81)	76	9519	215	123	1.82	0.3535
9	Elos 150W 10000K Plus DE 1	PFO 150W HQI (M81)	76	8678	208	122	1.82	0.3678
10	Giesmann 150W Marine DE 1	PFO 150W HQI (M81)	76	8640	203	122	1.79	0.3749
11	Ushio 150W 10000K DE 1	LampsNow 150W /175W Electronic	75	5994	179	119	1.74	0.419
12	Sylvania Aqua Arc 150W 10000K DE 1	Icecap 150W Electronic	75	8338	172	119	1.53	0.436
13	Sylvania Aqua Arc 150W 10000K DE 1	Reliable 150W Electronic	74	8380	168	120	1.53	0.4405
14	Ushio 150W 10000K DE 1	PFO 150W HQI (M81)	72	6462	202	119	1.83	0.3564
15	Icecap 150W 10000K DE 1	LampsNow 150W /175W Electronic	72	8595	178	119	1.71	0.4045
16	Sylvania Aqua Arc 150W 10000K DE 1	Aromat 150W Electronic	72	8427	163	120	1.48	0.4417
17	Icecap 150W 10000K DE 1 (new)	Current USA 150W Electronic	69	5819	165	122	1.44	0.4194
18	Icecap 150W 10000K DE 1 (new)	Aromat 150W Electronic	69	5904	163	122	1.42	0.4276
19	XDE 150W 10000K DE 1	Icecap 150W Electronic	68	9031	175	121	1.49	0.3886
20	XDE 150W 10000K DE 1	Giesemann 150W Electronic	67	8894	173	122	1.47	0.3873
21	Icecap 150W 10000K DE 1 (new)	Icecap 150W Electronic	67	5949	158	122	1.37	0.4272
22	Aqualine Buschke 150W 10000K DE 1	Reliable 150W Electronic	66	13033	168	119	1.53	0.3929
23	Aqualine Buschke 150W 10000K DE 1	Icecap 150W Electronic	66	12479	172	119	1.54	0.3837
24	Aqualine Buschke 150W 10000K DE 1	Aromat 150W Electronic	64	13155	163	120	1.47	0.3926
25	Ushio 150W 10000K DE 1	Reliable 150W Electronic	64	6487	168	120	1.52	0.381
26	Aqualine Buschke 150W 10000K DE 1	PFO 150W HQI (M81)	63	12229	191	120	1.74	0.3298
27	Ushio 150W 10000K DE 1	Icecap 150W Electronic	63	6462	168	120	1.49	0.375
28	Ushio 150W 10000K DE 1	Aromat 150W Electronic	62	6526	164	120	1.48	0.378
29	Elos 150W 10000K Plus DE 1	Current USA 150W Electronic	62	8819	172	122	1.48	0.3651
30	Icecap 150W 10000K DE 1	Reliable 150W Electronic	61	9195	167	119	1.51	0.3653
31	Icecap 150W 10000K DE 1	Icecap 150W Electronic	61	8996	168	120	1.51	0.3631
32	Elos 150W 10000K Plus DE 1	Aromat 150W Electronic	61	9019	163	122	1.42	0.3791
33	HIT(BLV) 150W 10000K DE 1	Icecap 150W Electronic	60	8502	168	123	1.45	0.3571
34	Giesemann 150W 10000K DE 1	Giesemann 150W Electronic	60	9844	175	120	1.5	0.3429
35	Elos 150W 10000K Plus DE 1	Icecap 150W Electronic	60	8869	158	123	1.37	0.381
36	Giesmann 150W Marine DE 1	Current USA 150W Electronic	60	8251	164	122	1.42	0.3659
37	Giesmann 150W Marine DE 1	Aromat 150W Electronic	60	8275	163	122	1.42	0.3699
38	HIT(BLV) 150W 10000K DE 1	Giesemann 150W Electronic	59	8822	174	122	1.48	0.3391
39	Giesemann 150W 10000K DE 1	Icecap 150W Electronic	59	9742	170	123	1.44	0.3471
40	Icecap 150W 10000K DE 1	Aromat 150W Electronic	59	8902	164	121	1.47	0.3598
41	Giesmann 150W Marine DE 1	Icecap 150W Electronic	58	8251	158	122	1.37	0.3696

Table 11: Comparison of the 150W 140000K DE lamps tested against all 150W DE 14000K lamps

	Lamp Name	Ballast Name	PPFD	CCT	Power	Volts	Amps	EFF
1	Icecap 150W 14000K DE 1 (new)	PFO 150W HQI (M81)	86	6415	203	122	1.79	0.4271
2	Icecap 150W 14000K DE 1 (new)	Current USA 150W Electronic	74	6036	172	122	1.48	0.4343
3	Icecap 150W 14000K DE 1 (new)	Aromat 150W Electronic	72	6217	163	122	1.42	0.4429
4	Icecap 150W 14000K DE 1 (new)	Icecap 150W Electronic	69	6158	158	123	1.36	0.4418
5	Giesmann 150W Coral DE 1	PFO 150W HQI (M81)	62	8930	208	122	1.82	0.3019
6	Giesmann 150W Coral DE 1	Current USA 150W Electronic	54	8832	173	121	1.5	0.3139
7	Giesmann 150W Coral DE 1	Icecap 150W Electronic	50	9035	158	122	1.37	0.3177
8	Giesmann 150W Coral DE 1	Aromat 150W Electronic	50	8972	163	122	1.43	0.3123
9	Aquaconnect 150W 14000K DE 1	PFO 150W HQI (M81)	46	0	195	122	1.7	0.2359
10	Aquaconnect 150W 14000K DE 1	Giesemann 150W Electronic	46	0	166	122	1.41	0.2771
11	Aquaconnect 150W 14000K DE 1	Icecap 150W Electronic	45	0	174	122	1.48	0.2586

Table 12: Comparison of the 150W 20000K DE lamps tested against all 150W DE 20000K lamps

	Lamp Name	Ballast Name	PPFD	CCT	Power	Volts	Amps	EFF
1	Radium 150W 20000K DE 1	PFO 150W HQI (M81)	58	0	228	122	1.98	0.2544
2	Radium 150W 20000K DE 1	Giesemann 150W Electronic	46	0	173	123	1.48	0.2659
3	Radium 150W 20000K DE 1	Icecap 150W Electronic	44	0	166	121	1.45	0.2651
4	Coralvue 150W 20000K DE 1	Icecap 150W Electronic	37	0	174	122	1.45	0.2126
5	Coralvue 150W 20000K DE 1	PFO 150W HQI (M81)	36	0	198	123	1.71	0.1818
6	Coralvue 150W 20000K DE 1	Giesemann 150W Electronic	36	0	178	123	1.45	0.2022
7	HIT(BLV) 150W Colorlite 20000K DE 1	PFO 150W HQI (M81)	35	0	202	121	1.82	0.1733
8	HIT(BLV) 150W Colorlite 20000K DE 1	LampsNow 150W /175W Electronic	34	0	175	120	1.7	0.1943
9	XDE 150W 20000K DE 1	Icecap 150W Electronic	32	0	173	123	1.45	0.185
10	HIT(BLV) 150W Colorlite 20000K DE 1	Icecap 150W Electronic	32	0	172	119	1.52	0.186
11	HIT(BLV) 150W Colorlite 20000K DE 1	Aromat 150W Electronic	31	0	164	121	1.48	0.189
12	XDE 150W 20000K DE 1	Giesemann 150W Electronic	30	0	168	120	1.42	0.1786
13	HIT(BLV) 150W Colorlite 20000K DE 1	Reliable 150W Electronic	30	0	168	119	1.54	0.1786
14	XDE 150W 20000K DE 1	PFO 150W HQI (M81)	28	0	181	123	1.61	0.1547
15	Icecap 150W 20000K DE 1 (new)	PFO 150W HQI (M81)	28	58681	184	122	1.65	0.1554
16	Icecap 150W 20000K DE 1 (new)	Current USA 150W Electronic	27	45956	158	123	1.38	0.1722
17	Icecap 150W 20000K DE 1 (new)	Icecap 150W Electronic	27	0	158	122	1.38	0.1747
18	Icecap 150W 20000K DE 1 (new)	Aromat 150W Electronic	26	53269	161	122	1.41	0.1671
19	Giesmann 150W Blue DE 1	PFO 150W HQI (M81)	25	0	191	121	1.71	0.1356
20	Giesmann 150W Blue DE 1	Aromat 150W Electronic	24	0	162	121	1.43	0.1481
21	Giesmann 150W Blue DE 1	Icecap 150W Electronic	24	0	158	123	1.36	0.1525
22	Giesmann 150W Blue DE 1	Current USA 150W Electronic	22	0	153	122	1.34	0.1444

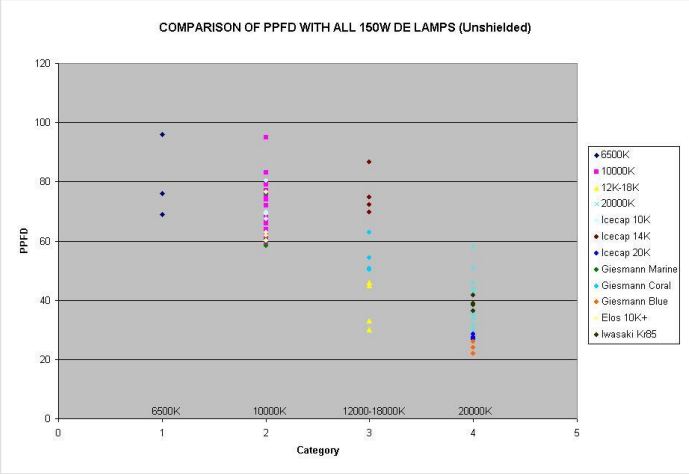

Figure 9: Comparison of the PPFD of the 150W DE lamps tested against all previously tested 150W DE lamps

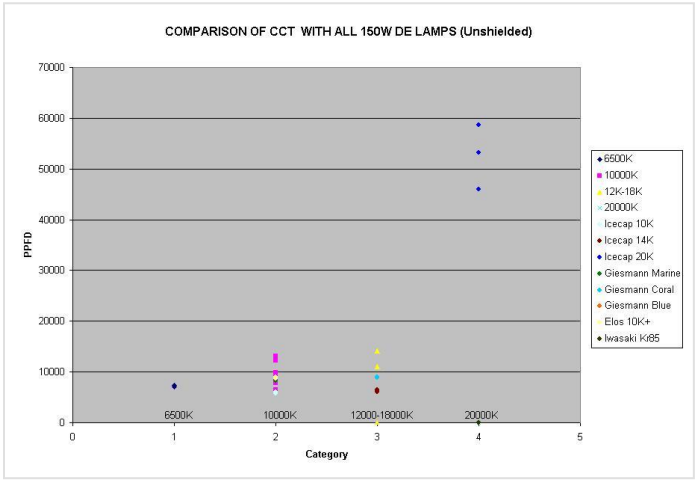

Figure 10: Comparison of the CCT of the 150W DE lamps tested against all previously tested 150W DE lamps

FEATURE ARTICLE

Total Organic Carbon (TOC) and the Reef Aquarium: an Initial Survey, Part I

By Ken S. Feldman, Kelly M. Maers

Department of Chemistry, The Pennsylvania State University, University Park, PA 16802. Ken and Kelly report on their work on Total Organic Carbon and how it relates to the reef aquarium.

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Link to original article: http://www.advancedaquarist.com/2008/8/aafeature3

These questions will be probed through review of the relevant literature on (non-aquarium) field studies and by experimentation on marine aquarium water samples taken from a range of aquarists' tanks:

- *What are Dissolved Organic Carbon (DOC), Particulate Organic Carbon (POC), and Total Organic Carbon (TOC)?*
- *What is the natural level of carbon (dissolved and/or particulate) in tropical reef waters? In the deep ocean?*
- *Which organisms produce carbon, and which organisms consume carbon in a reef environment?*
- *What role does organic carbon play in the health of the corals living in our marine aquariums?*
- *Might imbalances in carbon content underlie episodes of reef tank crashes?*
- *Do our reef tanks accurately mimic the natural levels of carbon on thriving reefs?*

Introduction: Plausible Connections between DOC, TOC, Coral Bacteria, and Coral Health

The economic value of coral reefs worldwide has been estimated at $375B/yr as a consequence of fishing, tourism, and coastal protection (Costanza, 1997). Unfortunately, in many areas of the world, the coral reefs are dying; for example, Caribbean reefs have suffered approximately an 80% loss in coral population over the past 30 years (Gardner, 2003). These interdependent facts have galvanized efforts amongst many areas of science to both identify the causative agents for the corals' (= reef's) demise and to pursue possibly ameliorative interventions. Many anthropogenic (= attributable to human activity) intrusions into the coral reef ecosystem have been recognized as contributing to the stress and even mortality of corals on tropical reefs, although naturally occurring stressors cannot be excluded either. All of this activity has brought into sharp focus the ecological significance of reef-building corals and their responses to changes in their environment. Many of the observations of coral distress/mortality made on tropical reefs can be duplicated in our (stressed) aquariums as a result of unplanned and unwelcome deviations in husbandry practices. Thus, maintaining the health and insuring the survivability of the fragile organisms that we so carefully cultivate in our home aquariums remains a significant challenge, especially as tanks age and waste materials can accumulate.

Fortunately, a great body of information, some anecdotal and some verified by rigorous experimentation, is available to the conscientious aquarist to aid in this task. Many (most?) of the canonical parameters associated with successful husbandry have been identified. Issues of lighting, flow, temperature, feeding, etc. usually can be addressed by several different and effective approaches. Maintaining water chemistry can be trickier, as consumption/removal and production/addition of key and trace water components must be balanced. Nevertheless, acceptable ranges for the major elements/compounds are documented, and the methodologies necessary to monitor and maintain appropriate levels of salinity, alkalinity, calcium, magnesium, strontium, iodide, nitrate, ammonia, phosphate etc., are well known and readily available. Missing from the above list of marine aquarium water components is one notable, perhaps even key, player: carbon.

What is Dissolved Organic Carbon (DOC), Particulate Organic Carbon (POC), and Total Organic Carbon TOC)?

Carbon in this context is a catchall phrase which refers to carbon-containing (i.e., organic) chemicals that are either dissolved in the water itself (= Dissolved Organic Carbon, DOC) or suspended in the water as small particles, including single-cell organisms (= Particulate Organic Carbon, POC) (Holmes-Farley, 2004). Together, these carbon sources are called Total Organic Carbon, TOC. The divide between DOC and POC is arbitrary and is based strictly on the capabilities of commercially available filtering materials. At present, the operational definition of DOC includes carbon-containing material that passes through the pores of a 0.2 micron filter. Any carbon-containing material left behind, which includes most bacteria/single-celled organisms, then is labeled Particulate Organic Carbon (POC) (Benner, 2002).

Organic carbon in both its particulate and dissolved forms has been called "the soil of the sea" in recognition of its role at the very

foundation of the entire marine ecosystem (Ducklow, 2002). It is the sustenance of the microbiota in the oceans and the entire marine food pyramid rests on the availability of this fuel source. Greater than 97% of the organic matter in the oceans is in the form of DOC, and attempts to quantitate the amount of DOC in all of the oceans' water leads to staggering values: 650 - 700 x 10^{15} grams of C, a number of the same order of magnitude as the total amount of carbon (as CO_2) in the atmosphere (~ 750 x 10^{15} grams) (Hedges, 2002; Benner, 2002).

The chemical makeup of this aggregate DOC remains largely a mystery as a consequence of difficulties in both separation and characterization of very small amounts of discrete molecules in exceedingly complex mixture of like species. Nevertheless, some progress has been made with the aid of modern separations (chromatography) techniques and sophisticated characterization methods (nuclear magnetic resonance, mass spectrometry) (Benner, 2002). Members of broad classes of biological metabolites have been identified, and the best estimates of DOC composition hover around the following values:

- ~ 6% of DOC from hydrolyzable sugars, including glucose, galactose, fucose, mannose and xylose.
- ~ 3% from hydrolyzable amino acids, including glycine, arginine, alanine, phenylalanine, serine, threonine, aspartic acid, valine, histidine, isoleucine, glutamic acid, lysine, methionine, and leucine.
- ~ 1% from hydrolyzable amino sugars, including *N*-acetyl glucosamine and *N*-acetyl galactosamine.

Thus, only about 10% of the total DOC can be accounted for by these common biochemical species; the remaining 90% of DOC remains uncharacterized. This unknown majority of carbon has been variously called "marine humic substances" or "refractory carbon", but these labels offer no useful chemical insight. In fact, even claiming that the carbohydrates and amino acids listed above are present in DOC is misleading; these species actually exist primarily as polymers, wherein many amino acids are connected together in a chain called a peptide or protein and many individual sugar molecules likewise

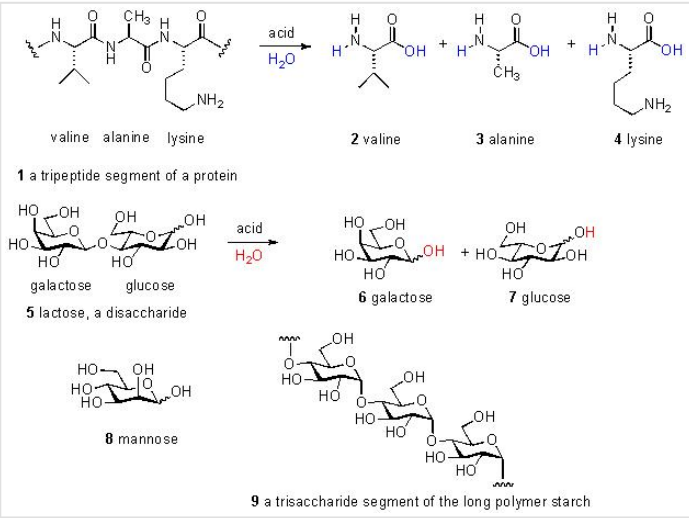


Figure 1. Examples of amino acids, peptides, sugars, and oligosaccharides.

are attached together in (sometimes branched) chains called oligosaccharides. Only through acid-catalyzed hydrolysis (= chemical addition of water) can these polymers be broken apart to their individual components and characterized as noted above. Some examples of these species as individual units, and as part of polymer chains, are shown in Fig. 1. The majority of the DOC in the oceans is consumed over a time span on the order of hours-to-weeks. The remainder eventually settles in the deep ocean, and ^{14}C (= radioactive carbon) dating techniques have placed its age in the 4000 - 6000 year range (Benner, 2002).

Examining the chemical structures illustrated in Fig. 1 emphasizes the fact that there are many other elements that are required to construct the molecules of life. The percentage of carbon (by dry weight) of different organisms has been measured/calculated, and reliable values for a few examples are: benthic invertebrates 30 - 49% C; pelagic invertebrates 45-50% C; humans 28% C (Liess, 2006; Sterner, 2002). Thus, when a value of 1 ppm of C is reported in an assay, the actual amount of organic material is somewhere between 2 and 3.3 ppm by mass.

What is the natural level of carbon (dissolved and/or particulate) in tropical reef waters? In the deep ocean?

The measurement of organic carbon levels (DOC and POC) in the oceans has had a long and colorful history. The first published attempts date back to 1892 by Natterer, and the topic has remained on the chemical oceanographers' vista since that disclosure. The detection of a small amount of carbon immersed in a "sea" of salt and inorganic carbon (bicarbonate, HCO_3^-) has proven to be a vexing challenge, and many methodologies have been explored. It was not until the 1990's that the currently "best" method emerged as a consequence of commercial instrumentation availability, although "home-made" versions of the key instruments date back to the 1960's. This method, called High Temperature Oxidative Combustion (HTOC), literally burns all organic residues in a sample to generate CO_2 from the carbons, and then that newly formed CO_2 can be identified and quantified with the appropriate detector. Even with this advance, issues with high instrument "blanks" plagued early attempts to gain useful data on ocean DOC levels, but a conference in 1991 and subsequent follow-ups has led to a regularization of the methodology with respect to sample preparation and appropriate blank utilization (Sharp, 1993; Sharp, 2002).

The commercial instrument of choice is the Shimadzu 5000 TOC Analyzer. After the instrument details were worked out, many reliable measurements of DOC, POC, and TOC content on reefs and in the open ocean were documented, Table 1. The generally accepted value of deep ocean TOC (DOC in this instance) ranges from ~ 0.45 - 0.60 ppm, a number that appears to be insensitive to collection location. On reefs, however, the DOC (and TOC) value is considerably higher. Even with this point noted, the values of DOC on reefs from the South Pacific to Japan to the Caribbean to the Red Sea are remarkably consistent in their range: 0.7 - 1.6 ppm. Anomalously high values for some sites at Ponape Island were attributed to terrestrial runoff (= pollution), similar to the high values seen in Tokyo Bay and Florida Bay. Thus, there appears to be a consensus value of 1.1 ± 0.4 ppm of carbon in the bulk water of healthy thriving reefs. These reefs, at least in the South Pacific, are just the types of ecosystems which harbor the corals, fish and other livestock that make up our aquarium biota.

Which organisms produce carbon, and which organisms consume carbon in a reef environment?

The major consumers of the DOC in the reef environment are heterotropic (= can't make their own food) bacteria (Moriarty, 1985). These bacteria can be living in the water column or tightly associated with substrate, detritus, corals and other benthic organisms, etc. Bacteria are a critical component in the food web of the reef, as they occupy the role of "middle man" in the transfer of energy from the source (= sunlight) to the consumers on the reef (Eppley, 1980; Ducklow, 1983, Crossland, 1980; Johannes, 1967; Ducklow, 1979; Gottfried, 1983). Sunlight impinging on the reef kicks off the energy cycle by promoting photosynthesis within free-swimming plankton in the water column and also within the zooxanthellae of the scleractinian corals that we obsess about in our aquaria. Photosynthesis utilizes the sunlight's energy to "fix" (= attach) inorganic carbon in the form of CO_2 to organic chemical structures that eventually become carbohydrates (cf. Fig. 1). These carbohydrate building blocks are chemically manipulated further by the zooxanthellae and/or the coral host and then secreted by the coral as coral mucus (a combination of complex polysaccharides, amino acid oligomers/polymers, lipids, etc., cf. Fig. 1). The carbohydrates and amino acids within the mucus serve as food sources for the bacteria and other microbiota that comprise the foundation of the marine food pyramid (Kirchman, 1990; Rich, 1996; Weiss, 1999; Wild, 2004; Sharon, 2008). The remaining reef inhabitants, including the very corals that house the zooxanthellae, then feed on these energy rich microbes (or, in turn, on the organisms that eat the microbes, ad infinitum), thus perpetuating the reef's nutrient recycling food web. In addition to corals, sponges are some of the most prolific repositories of marine bacteria. In fact, some sponges have been studied as

Table 1. A survey of organic carbon measurements at reef (Entries 1-17) and non-reef ocean sites (Entries 18-24) from around the world. All data obtained with a Shimadzu 5000 TOC Analyzer (HTOC method) unless otherwise indicated. Note that all raw data were converted to ppm units for consistency of comparison.

Entry	Location	Depth(ft)	DOC(ppm)	POC(ppm)	TOC(ppm)	Ref.
1	Haraiki lagoon, FP[a]	27	0.76	0.17	0.93	Pagès (1997)
2	Hikueru lagoon, FP	58	0.93	0.11	1.04	Pagès (1997)
3	Hiti lagoon, FP	26	0.92	0.12	1.04	Pagès (1997)
4	Kauehi lagoon, FP	104	0.82	0.09	0.91	Pagès (1997)
5	Marokau lagoon, FP	65	0.85	0.11	0.96	Pagès (1997)
6	Nihiru lagoon, FP	58	0.72	0.11	0.73	Pagès (1997)
7	Rekareka lagoon, FP	3	1.00	0.22	1.22	Pagès (1997)
8	Taiaro lagoon, FP	39	1.67	0.19	1.86	Pagès (1997)
9	Tekokota lagoon, FP	10	0.72	0.09	0.81	Pagès (1997)
10	Tepoto Sud lagoon, FP	16	0.74	0.12	0.86	Pagès (1997)
11	Majero Atoll, Marshall Is.	<1	0.62-2.18[c]			Yoshinaga (1991)
12	Ponape Island, Micronesia	<1	1.61-4.51[c]			Yoshinaga (1991)
13	Great Astrolabe lagoon, Fiji	65-120	1.37			Torréton (1999)
14	Shiraho reef, Japan	<1	0.86	0.04	0.90	Hata (2002)
15	Curacao, NA[b] (day)	23	1.55[d]			van Duyl (2001)
16	Curacao, NA (night)	23	1.16[d]			van Duyl (2001)
17	Coral Reef Nat. Res., Israel	29	0.86	0.09	0.95	Yahel (2003)
18	Tokyo Bay	<1	1.92			Ogawa (1992)
19	open ocean, Majero Atoll	1-162	0.88-1.66[c]			Yoshinaga (1991)
20	open ocean, eq. Pacific	<1		< 0.06	0.84	Sharp (1995)
21	open ocean, eq. Pacific	13000		< 0.01	0.47	Sharp (1995)
22	open ocean, near FP	--	1.00	0.05	1.05	Pagès (1997)
23	open ocean, Sargasso Sea	6	0.88			Sharp (1993)
24	open ocean, Sargasso Sea	7150	0.59			Sharp (1993)
25	Florida Bay, Florida	<1			10.5	Boyer (1997)

[a]French Polynesia. [b]Netherlands Antilles. [c]Range of several collection sites. [d]Wet chemical oxidation method, cross-correlated with HTOC method.

effective bioremediation agents in marine aquaculture as a consequence of their exceptional ability to absorb TOC (Fu, 2007).

Where does the DOC come from? Phytoplankton are major contributors, and the intriguing hypothesis that DOC release is a means to dispose of excess, photosynthetically generated "fixed" carbon when nutrient levels are not high enough for growth, has been proposed (Hessen, 2008). As discussed above, some of the major producers of DOC on the reef are the corals themselves (Crossland, 1987). Using some rather creative carbon-balance accounting, Sorokin has estimated that ~ 20% of the DOC in the waters of a tropical reef can be attributed to coral mucus production (Sorokin, 1993). In an independent study, a similar value (10 - 20%) of the total TOC that is metabolized by the reef's sedimentary community was attributed to coral mucus (Wild, 2004); Johannes, using different estimation methodology and at a different locale, scales this value back to ~ 2% (Johannes, 1967). Even given the large error bars in these numbers due to the assumptions made, it is astonishing that the corals contribute so much organic material to the reef water column, and by inference, to the closed systems of our (overstocked?) reef aquariums.

Several additional lines of evidence support the contention that corals, via their mucus secretions, literally flood the reef with DOC. For example, measurement of the DOC content of the contact surface water surrounding *Montastraea faveolata* and *Madracis mirabilis* on a reef near Curacao NA resulted in higher values (~ 2.28 ppm) compared with nearby reef water (1.60 - 1.94 ppm) (van Duyl, 2001). In another (laboratory-based) study, *Galaxea fascicularis* was observed to emit a DOC "spike" every morning and every afternoon lasting about an hour. Specimens fed with artemia secreted a larger DOC spike compared to unfed control: for the fed *Galaxea*, the measured DOC value within a 5 liter reservoir raised from a base value of 1.2 ppm up to 4.8 - 20.4 ppm; unfed *Galaxea* raised the base DOC level of the water only a few ppm during the spike emission. In both cases, within 2 hours of the spike, the DOC content of the reservoir fell back to basal levels (Ferrier-Pagès, 1998). Carbon balance calculations suggested that ~ 11-14% of the photosynthetically fixed carbon (i.e., originating in HCO_3^- <-> CO_2) is released as DOC, a value in line with many prior studies (Sorokin, 1993; Crossland, 1987).

Where does the DOC go when the *Galaxea* spike subsides? ^{14}C labeling studies suggest that it is rapidly consumed by bacteria that live in and on the coral itself and not by bacteria present in the water column. Shutting down these endogenous bacteria by antibiotic treatment abolished DOC uptake.

In a subsequent study, Ferrier-Pagès and colleagues expanded this type of experiment to include a more richly diverse coral tableau in their laboratory aquarium (Ferrier-Pagès, 2000). Specimens of *Stylophora sp.*, *Acropora sp.*, *Favia sp.*, *Galaxea sp.*, and *Euphyllia ancora* in one experimental tank, and similarly, *Montipora sp.*, *Favia sp.* and again *Euphyllia ancora* in a second independent tank, were treated with microplankton (tank 1) and marine bacteria (tank 2). In both cases, a DOC increase of 5 - 13-times baseline was detected 2 - 7 hrs after feeding. These DOC bursts subsided after about 2 hrs and the DOC level dropped to pre-feeding values. A control tank (substrate but no corals) did not exhibit any surge of DOC during the course of the experiment. Means and Sigleo can be credited with similar observations on *Acropora palmata* as well (Means, 1986). Taken together, these consistent observations of a correlation between coral feeding and subsequent DOC production and then consumption, across a wide range of coral species and food types, begin to speak to the generality of the phenomenon. In fact, these observations might foreshadow the development of a hypothesis positing that the coral deliberately regulates the amount and content of its bacterial population by metering out food in the form of DOC (see Rohwer, below).

The apparently tight coupling between corals and their associated microbiota, possibly at least partially mediated by DOC production/consumption, suggests that the overall "health" of this bacterial population might impact on the overall health of the coral itself. This concept has been expanded and codified by Rosenberg as "the hologenome theory of evolution", which stipulates that a host organism (i.e., coral) and its associated microbiota (bacteria, zooxanthellae, etc.) should be viewed as a single unit of evolution; the *holobiont* (Rosenberg, 2007). The value of this perspective can be seen when considering the reproduction time of bacteria (minutes) compared with the reproduction time of corals (months? years?). The genetic information of the microbiotic symbionts can change much more rapidly through mutation and/or horizontal gene transfer than can that of the host coral, ensuring that the holobiont can more rapidly adapt via natural selection to quickly changing environmental conditions. In support of this concept, measured bacterial populations in the coral mucus layer are 100 - 1000x that in the surrounding water. In addition, work by LaJeunesse has demonstrated that there is a correlation between host coral species and the specific clade(s) of zooxanthellae (= symbiotic algae) that associate with it, and that these correlated associations are responsive to evolutionary pressure (LaJeunesse, 2005a; LaJeunesse, 2005b; see also Baker, 2003). Likewise, similar bacterial population compositions are found in the same species of coral at differing geographic locations, whereas juxtaposed corals of different species have largely different bacterial components to their holobiont (Rohwer, 2001, 2002; Bourne, 2005; Rosenberg, 2007; Ritchie, 2008). Alternatively, some evidence has emerged that implicates environmental gradients (e.g., depth, pollution) as determinants of bacterial populations (Klaus, 2007). Thus, whereas the final picture of coral/bacteria association is undoubtedly going to be complex and multifactoral, there appears to be some measure of persistent coral-microbe selectivity indicative of purposeful matching of symbiont with host. Do corals and their associated microbiota in our aquaria respond similarly to the corals studied on reefs? Preliminary evidence suggests that, in fact, the microbial population of identical *Fungia granulosa* corals in aquaria and in the wild is different enough to be a point of interest (Kooperman, 2007). The authors suggest that the differences in microbiota in the aquarium specimens vs. the reef specimens are an example of the adaptability of the coral holobiont to its environment. It is intriguing to speculate that corals deliberately control their bacteria population to confer a survival advantage, and that DOC secretion may be one mechanism by which this control is implemented. Some encouraging circumstantial evidence on this point has been recorded. For example, different species of algae contribute compositionally different DOC, and those differences in chemical composition apparently correlate to the recruitment of different bacterial species (González, 2000; Pinhassi, 2004; Grossart, 2005; see also Covert, 2001 for a related example). More specifically, laboratory treatment of oceanic water samples containing both the marine bacteria *Pseudoalteromonadaceae* (P) and *Alteromonadaceae/Cotwelliaceae* (A/C) with defined inputs of various carbohydrates and amino acids (as models for DOC components) led to conspicuous differences in the P:A/C ratio as a function of carbon source input (Allers, 2007a; Allers, 2007b). Finally, the observation has been made that (1) the chemical composition of coral mucus differs between species (Meikle, 1988), and that (2) different genetic variants of the water- and coral-born bacteria

Alteromonadaceae macleodii associate with different corals (Bourne, 2005; Lampert, 2006); could (1) correlate to (2) in a deterministic way?

WHAT ROLE DOES ORGANIC CARBON PLAY IN THE HEALTH OF THE CORALS LIVING IN OUR MARINE AQUARIUMS?

If DOC is a factor in microbiota control and maintenance within the coral holobiont, then what happens when something goes "wrong"? This question is currently at the forefront of coral microbiology research, given the backdrop of reef crashes and coral mortality in the Caribbean in particular and also around the globe (Rosenberg, 2007b). A few examples serve to illustrate some coral pathologies associated with problems arising in the microbial assemblage of certain corals. Perhaps the best-studied case involves bleaching of the Mediterranean coral *Oculina patagonica*. Bleaching was proposed to be a direct consequence of infection by the bacteria *Vibrio shiloi* (Rosenberg, 2007a). Whether this bacterium invades and then overwhelms the native biota, or whether it is always present but held in check, is unknown. In either case, once present, raised water temperatures appear to initiate a series of biochemical processes in *V. shiloi* that ultimately led to bleaching of the host coral. This explanation for *O. patagonica* bleaching has been challenged recently, and alternative hypotheses that do not require bacterial invasion have been proposed (Ainsworth, 2008).

Rohwer and colleagues recently have published two provocative papers that attempt to link DOC levels with bacterial population levels in the holobionts of certain corals, and ultimately to the health of the corals themselves (Kuntz, 2005; Kline, 2006). Treatment of encrusted fragments of *Montastraea annularis*, *Agaricia tenufolia*, and *Porities furcata* in a controlled laboratory setting with 5 mg/L (= 2 ppm of C) of lactose, a disaccharide (see Fig. 1), killed most of the *A. tenufolia* specimens over 30 days, but did not cause any increased mortality vs. control for the *M. annularis* and *P. furcata* samples. However, a similar 30-day experiment with 25 mg/L of lactose (= 10 ppm of C) led to almost complete mortality with the *M. annularis* and *A. tenufolia* of course, but *P. furcata* remained unperturbed. Extension of this experimental protocol to other sources of carbon led to similar results. Mannose (a monosaccharide, see Fig. 1) at 25 mg/L (= 10 ppm of C) was particularly lethal to *P. furcata*, but not to *M. annularis*. Starch (a polysaccharide, see Fig. 1) at 25 mg/L (10 ppm of C) on the other hand, posed no threat to *P. furcata* but was deadly to the *M. annularis* samples. The resilience of *P. furcata* to all insults (except mannose!) was not unexpected, as this coral has adapted to life in far-from-pristine environments that suffer wide fluctuations in temperature, sedimentation and salinity. With this exception noted, these experiments, for the first time, provide unambiguous evidence for coral mortality as a consequence of exposure to carbohydrates that are related to components of DOC in the oceans.

What is the biochemical connection between carbohydrate dosing and coral mortality? These elevated carbohydrate levels, as surrogates for DOC, lead to a order-of-magnitude increase in microbial growth rates within the subsurface mucopolysaccharide layer of *Montastraea annularis* (Kline 2006). Interestingly, dosing *M. annularis* frags in a laboratory aquarium with a bolus of bacteria cultured from the subsurface mucopolysaccharide layer of several corals (*Montastraea franksi*, *Agaricia tenufolia*, *Porites astreoides*, and *Diploria strigosa*) killed the coral directly (Kline, 2006). This treatment did no more than essentially instantaneously double the coral's bacterial population; it did not introduce any new pathogenic bacteria to the coral. In addition, the expressed pathologies of the dying corals upon carbohydrate dosing resemble the symptoms of several bacterially induced coral band diseases. This circumstantial evidence encouraged Rohwer et al. to speculate that the introduction of carbohydrates (= a fuel source) will generate an imbalance in the bacterial component of the holobiont, and that this departure from equilibrium leads to coral mortality. The mechanism by which this induced bacterial proliferation causes coral death remains to be elucidated, and this pivotal issue must be addressed before this intriguing hypothesis can gain further traction. Nevertheless, the empirical evidence can be construed to support a robust relationship between elevated DOC levels, correspondingly increased bacterial populations, and coral mortality.

Any discussion on the relationship between DOC levels and coral health would be remiss without a digression into the currently popular practice of dosing reef tanks with carbon sources, specifically vodka (= ethanol), sugar, and/or vinegar (see http://glassbox-design.com/2008/achieved-through-observation-and-experimentation/ for a timely discussion). The logic behind this husbandry technique stems from the speculation that the increase in DOC provided by these chemicals will promote bacterial growth, and this increase in bacterial growth will in turn boost the removal of nitrogen and phosphorus-containing nutrients from the water column. The increased bacterial mass can then be removed by efficient skimming, leading to a net export of undesirable nutrients (N, P) from the aquarium. A standard recipe has been developed by Eric of Glassbox-Design: 200 mL of 80-proof vodka, 50 mL of vinegar, and 1.5 tablespoons sugar, mixed together. The dosing recommendation with this mixture involves starting with 0.1 mL/20-gal per day, and gradually increasing to a maintenance dose of 0.5 mL/20-gal per day. How do these carbon input values compare to the carbon (via carbohydrate) input values of Rohwer? In fact, the Eric/Glassbox-Design protocol is equivalent to raising the aquarium water by about 1.1 ppm of C at the maintenance dose. The Rohwer carbon dosing values that led to coral mortality over a 30-day exposure were in the range 2 - 10 ppm of C. So, it appears that the Eric/Glassbox-Design recipe does not leave much margin for error in dosing levels; overdosing by 2-3X might lead to coral mortality.

MIGHT IMBALANCES IN CARBON CONTENT UNDERLIE EPISODES OF REEF TANK CRASHES?

The inexplicable mass mortality of corals in seemingly healthy reef aquaria remains one of the most perplexing and frustrating events in the hobby. Reef bulletin boards all too frequently contain threads that begin "Help! My tank is crashing; my corals are dying, but all of my measurable water parameters are within expected ranges. What's wrong?" Could it be possible that elevated levels of DOC, for whatever the reason, are contributing to, or even causing, the coral loss? Might increases in DOC lead to runaway growth of the corals' bacterial symbiont population that in turn might precipitate a critical imbalance in (some of) the bacterial components of the coral holobiont? These questions are not answerable at present, since there is a complete lack of data on DOC (or TOC) levels in marine aquariums. Thus, basic data like basal TOC levels in successful aquariums, and how those levels might change in response to various stimuli (i.e., tank inhabitants, feeding, different husbandry techniques, ± skimming, ± GAC, ± ozone, etc) have yet to be recorded. Only after a broad and comprehensive database of marine aquarium DOC (TOC) levels has been compiled can some judgments about the

significance of DOC levels on coral (and overall livestock) health be offered.

A first attempt to acquire some of these data is described below.

Do our reef tanks accurately mimic the natural levels of carbon on thriving reefs?

Accurate and reliable reports of DOC and/or TOC levels in thriving reef aquariums have not yet been reported. However, this type of information is essential for evaluating the hypothesis that DOC/TOC levels can impact on the health of the livestock, particularly the corals, in this captive environment. Measured DOC/TOC values in tanks that were established and maintained under different types of husbandry protocols can begin to provide glimpses into that part of the relationship between "aquarist style" and overall outcome (i.e., coral health) that is mediated by the water's carbon content. In order to approach this goal, an initial series of studies on the author's reef aquarium were performed. TOC and not DOC was chosen as the measured parameter, because measuring DOC would (1) require filtration of the tank water samples prior to analysis in order to remove POC (particulate organic carbon). Other researchers have found that this filtration procedure contaminates samples with carbon. On this point, control experiments showed that 0.2 micron filters required washing with as much as 50 mL of ultrapure MilleQ distilled/RO/DI 18.2 M water in order to diminish the carbon measurement of a water sample to pre-filtering levels. That operation was not practical for the amount of samples examined. (2) Eliminate the POC component, which is also a food source, and (3) provide no further useful information, as DOC is typically > 95% of TOC in any event. The Shimadzu 5000 TOC analyzer, the same instrument/method used in the authentic reef TOC/DOC measurements reported in Table 1, was used in these experiments as well. Each data point was recorded as the average of three independent measurements on samples drawn within 1 minute of each other.

Experimental protocol: Each sample was collected by dipping an inverted 40 mL pre-washed I-CHEM custody seal vial (VWR catalogue # 15900-022) under the surface of the aquarium to a depth of about 6 inches, and then rotating it so that it filled with tank water. There is some discussion in the aquarium hobby that the surface of a reef tank collects organics at the air-water interface, but our measurements of TOC content in surface water vs. 6" depth water vs. 24" depth water provided no support for that hypothesis. The vial was immediately removed, sealed with a Teflon-septum cap, labeled, and the cap area was tightly covered with aluminum foil to exclude dust from settling on the Teflon septum. The vial was then placed in a -23 ^{o}C freezer to quickly freeze the contents. The vials from an experiment were collectively thawed in warm water and submitted to the Shimadzu Analyzer within 60 min of removal from the freezer. A sample of 18.2 M water was added directly to a clean vial as a blank, and the TOC reading from that blank was subtracted from the TOC values of all of the samples. Typical blank readings ranged from ~ 0.12 ppm to 0.25 ppm. Experience with the Shimadzu instrument suggests that the origin of this "blank" carbon lies with residue in the combustion tube itself, and not in the 18.2 M water. Thus, blank subtraction is a legitimate and necessary component of the analysis. The TOC Analyzer reports ppm C values based on a calibration curve using potassium hydrogen phthalate as a standard, over the range 0.5 ppm to 11 ppm of C. Using this particular calibration chemical, and preparation of the calibration curve, is standard operating procedure with the Shimadzu 5000. Each sample is analyzed 3 - 5 separate and independent times, until the spread of the TOC values falls within a preset range. An example of a typical output is shown in Fig. 2.

The TOC content of the author's tank, and ORP readings at the same time points, were measured over the course of a typical week, Fig. 3. This tank is a 175 Oceanic bowfront equipped with a sump holding a total water volume of 167 gallons (Feldman, 2006). A survey of the livestock contained in this reef tank can be seen in Figs. 7 and 8. No change in stocking occurred during the experimental period. A 17% water change was conducted at T = 0 hr, and then water samples (in triplicate) were removed at several intervals during the day, for 7 days (until the next water change). The lighting schedule is illustrated in Fig. 3; illumination was provided by two 400W Geismann 14K MH bulbs and one 175W Iwasaki 15K bulb. An H&S A200/1260 skimmer was run continuously except for a 2-hr time period after the heavy feedings. A calcium reactor and a UV sterilizer were run continuously. The water temperature was held at 75 - 77 ^{o}F by heaters and a chiller slaved to an Aquacontroller II. Water circulation was provided by a SeaSwirl on the sump return, two Vortek MP40w pumps and one Tunze 6100 pump. The feeding schedule is illustrated as F1 (heavy feeding) or F2 (light feeding) on the graph of Fig.

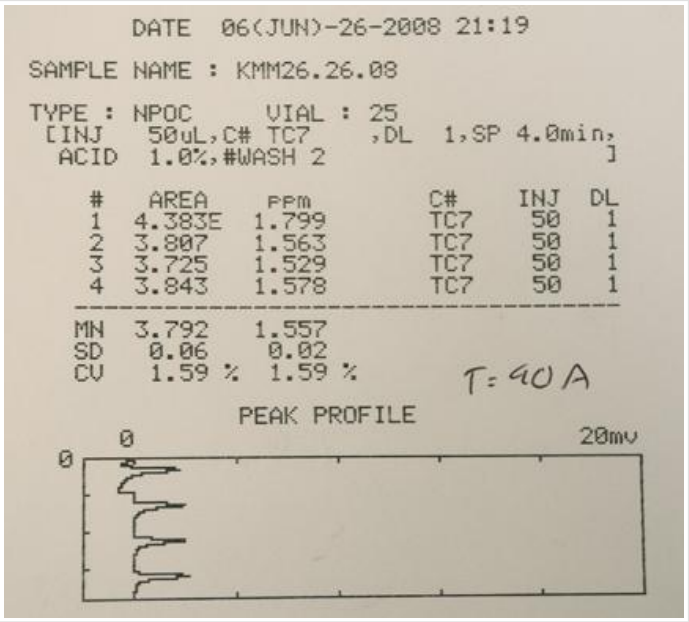


Figure 2. Aquarium researcher Kelly Maers and the Shimadzu 5000 TOC Analyzer; an example of a typical experimental TOC output.

3, and actual food portions are pictured in Fig. 4. The fish eat the larger chunks of meaty food, whereas the fine particles of zooplankton, phytoplankton, cyclopeeze and even copepods are more geared to the feeding requirements of the various invertebrate filter feeders, including the large- and small-polyped corals. The fish readily consumed their portion of the heavy feeding's food over the course of 1-3 min. The light feeding's food (Formula 1) was consumed primarily by the *C. interruptus* over approximately a 10-min period.

Even cursory inspection of the data displayed in Fig. 3 reveals five immediate conclusions: (1) the TOC level is responsive to food addition, with maxima occurring approximately 6 - 9 hrs after (heavy) feeding. (2) The overall TOC levels span a range (~ 0.7 ppm - 1.4 ppm) that is completely coincident with values observed in the water over tropical reefs (cf. Table 1). (3) There is no useful correlation between TOC values and ORP values. (4) The illumination cycle didn't seem to influence the TOC levels. (5) Only the heavy feedings appear to contribute materially to the TOC level; the light (Formula 1) feedings, which consisted of food not sized appropriately for immediate consumption by corals, bacteria or other filter feeders, has no measurable effect on TOC levels. It is rapidly eaten by the interruptus before it has a chance to work its way down to the lower levels of the food chain.

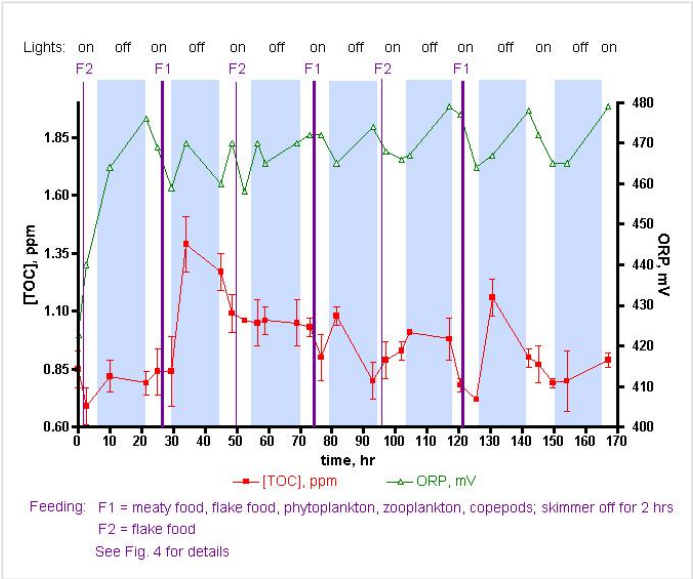

Lights: on off on off on off on off on off on off on off on
F2 F1 F2 F1 F2 F1
[TOC], ppm
ORP, mV
time, hr
[TOC], ppm
ORP, mV
Feeding: F1 = meaty food, flake food, phytoplankton, zooplankton, copepods; skimmer off for 2 hrs
F2 = flake food
See Fig. 4 for details

Figure 3. A week in the life. Total Organic Carbon (TOC) and Oxidation/Reduction Potential (ORP) measurements over the course of a week for the author's reef tank.

Looking beyond the obvious, two intriguing questions emerge from considering the rise and fall of TOC levels after heavy feeding. The

Figure 4. Examples of food used in the "week in the life" tank study.

results of Ferrier-Pagès on the *Galaxea fascicularis* system provide guidance on these topics.

1. What is the origin of the TOC spike that appears after feeding?
2. What is the origin of the post-spike TOC decrease?

What is the origin of the TOC spike that appears after feeding?

In the several corals examined by Ferrier-Pagès and independently by Means, a delay in DOC level rise following feeding was observed, suggesting that secondary organic molecule emissions and not primary food particulates were responsible for the elevation in DOC levels. Argument-by-analogy suggests that the TOC spike in the author's tank therefore is not likely due to the food itself. Consistent with this interpretation are the observations that (a) there was no visible evidence of food particulates in the water samples, and (b) the immediate TOC measurement 2-3 hr after heavy feeding did not display elevated TOC levels; in fact the TOC level actually decreased slightly during that time period. It was only approximately 6-9 hrs later that the TOC level peaked. Similar delays were documented in the Ferrier-Pagès studies. In both the various Ferrier-Pagès studies and in the author's tank, the several-hour delay between feeding and TOC discharge is consistent with the intervention of coral-based metabolic processes that convert food into emitted DOC, the signature of which is coral mucus secretion. Of course, other tank inhabitants absent in the Ferrier-Pagès work might contribute to DOC emissions as well.

What is the origin of the post-spike TOC decrease?

The fairly rapid decrease of TOC levels after the post-feeding spike also is reminiscent of the behavior of the various corals of Ferrier-Pagès. In fact, the TOC levels return to values very near the pre-feeding ones within a specific number of hours in both the Ferrier-Pagès studies (~ 2 hrs) and the week-in-the-life study of Fig. 3 (< 10 hrs). The *Galaxea* system observations were interpreted by Ferrier-Pagès as evidence for DOC consumption by coral bacteria. In addition, the carbohydrate dosing experiments of Rohwer indirectly support the notion that the coral bacteria in the author's tank are prime consumers of TOC.

On the other hand, the TOC decrease in the author's tank also might fall within the expectations of nutrient export via protein skimming as provided by the H&S A200, a device absent in the *Galaxea* experiments. Is it just TOC consumption by coral bacteria and possibly other microbiota, or does the aggressive skimming of the H&S A200 contribute to the general drop in TOC levels by physically removing at least some components of TOC? Using Ferrier-Pagès experiments as a guide, it is not necessary to invoke skimmer participation; the drop in TOC levels may be attributable largely to coral bacteria feeding. But, is that the whole story, or does the skimmer contribute to the TOC depletion as well? This question can be answered through the experiments illustrated in Figs. 5 and 6.

The data of Fig. 3 were taken under routine tank husbandry conditions that including turning the skimmer off for 2 hrs after heavy feeding. In order to focus on the TOC depletion capabilities of the skimmer itself, a pair of skimmer-on/skimmer-off trials was run on successive days. On the first day, the tank was heavily fed and the TOC level was monitored every 15 minutes for 2 hrs. The skimmer was off during the feeding and the 2 hr experimental time period. On the second, day, the skimmer was left on during the feeding and subsequent 2 hr period. The TOC levels under both experimental regimes were remarkably similar, Fig. 5. In both cases, the TOC level elevated, but the relative increase in the skimmer-on case was only half that seen in the skimmer-off experiment (22% vs. 45%, respectively). In neither case did the TOC level drop significantly over the 2 hr experimental period. Based on these data, it is possible that the skimmer marginally removes some TOC early in the experiment, but the impact is not dramatic. The TOC data from these experiments covers a region in time (the first two hours after feeding) that was not examined in the week-in-the-life measurements; therefore, it is not possible to draw any conclusions about whether these data sets are similar to, or disparate from, the week-in-the-life data.

The data displayed in Fig. 5 was intriguing and also counterintuitive in that it appears to assign a rather limited role to the skimmer in depleting the aquarium water of TOC. However, the short experimental time frame might provide an incomplete picture of the skimmer's effect; perhaps examining the TOC level over a longer period of time under skimmerless conditions will provide more conclusive evidence on the role of the skimmer one way or the other. Therefore, the skimmer-off experiment was repeated, with data collection continuing over a 24 hr period, Fig. 6. The TOC level spiked

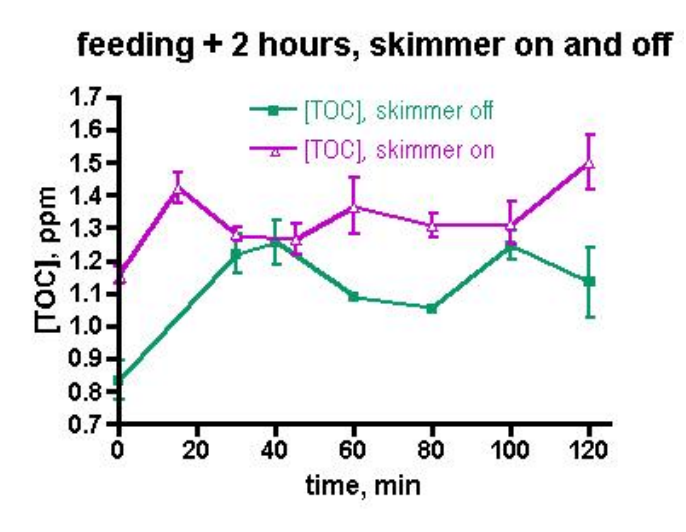


Figure 5. TOC levels with and without active skimming, up to 2 hrs after feeding.

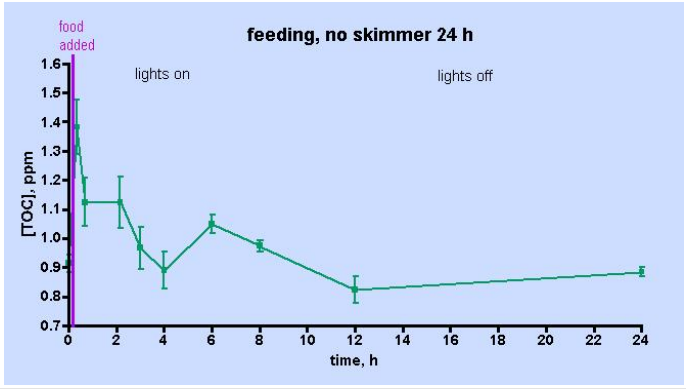
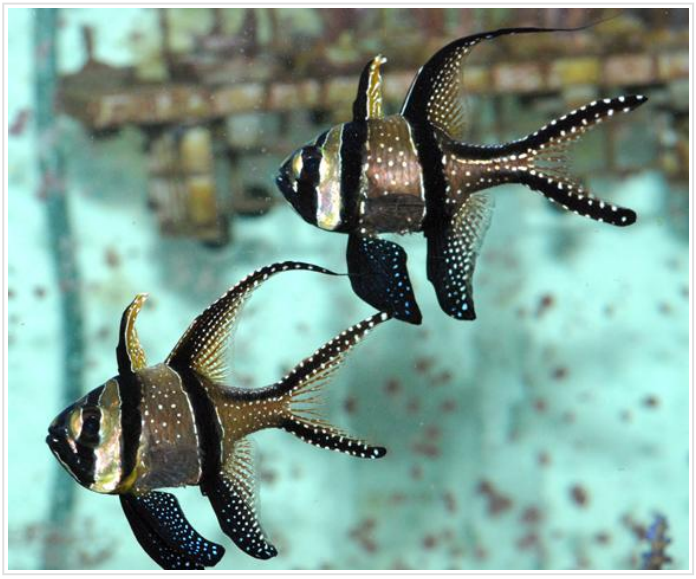


Figure 6. TOC levels over a 24 hr period after feeding, with the skimmer off.

after about 30 min (~ 50% increase) and then it begins to decrease by the 1 hr mark. *In total, these data unequivocally demonstrate that the H&S skimmer is not required to deplete the aquarium water of TOC. Apparently, naturally biological processes are sufficient in and of themselves to return the post-feeding TOC levels to their pre-feeding values after about 4 hrs or so.* A small spike follows at the 6 hr mark, an increase in TOC level similar to that seen at 6-9 hr after heavy feeding in the "week-in-the-life" data of Fig. 3. After that spike, the TOC level declines to the pre-feeding value by the 12- and 24-hr marks; again similar behavior was seen in the "week-in-the-life" data. Thus, the post-feeding TOC decrease displayed in the data of Fig. 3 can be explained by simply citing TOC consumption (by coral bacteria?) and not TOC removal by the skimmer. The skimmer may in fact contribute to the depletion of TOC, but its participation is not required by the data. Clearly the skimmer is doing something, given the copious residue accumulated in the collection cup at the end of the week. Perhaps, however, the residue removed by the skimmer is only a rather small, even inconsequential, portion of the entire TOC load that develops in the aquarium water over the course of a week as a consequence of both feeding and all of the photosynthetic activity (CO_2 --> organic carbon (carbohydrates)) contributed by the tank's phototrophic (= conducting photosynthesis) inhabitants. If the skimmer was much more efficient at removing TOC than it appears to be, then perhaps the TOC level within an aquarium might drop down below the "healthy reef" region defined by the data in Table 1 and into the oligotrophic (= nutrient poor) region of the deep ocean, an environment not hospitable to corals (cf. Table 1). That type of TOC decline might prove disastrous for the coral holobiont, which presumably has evolved to thrive in waters with a TOC content in the 0.7 - 1.6 ppm range. This provocative speculation really raises the question, "Is it necessary to purchase a large "killer" skimmer, or will a more modestly priced and smaller unit serve equivalently for keeping the TOC level in the range acceptable to corals and other inhabitants of our reef aquariums?"

Editor's Note: Part II of this article will be published in next month's Advanced Aquarist.

Fish population in the author's tank during the "week in the life" study:



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The preeminent magazine for the dedicated reefkeeper

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REEFKEEPING EVENTS

What's Happening in Your Area?

By Advanced Aquarist Readers

Check to see if an event is happening in your area!

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Keywords (AdvancedAquarist.com Search Enabled): Advanced Aquarist Readers, Reefkeeping Events
Link to original article: http://www.advancedaquarist.com/2008/8/events

Do you have an upcoming event?

If so, please email us at feedback@advancedaquarist.com and let us know about it!

Summary of Upcoming Events

1. MACNA XX, September 5 - 7
2. West Tennessee Frag Swap and Aquarium Show, September 27
3. Southern Colorado Marine Aquarist Society Frag Swap, October 4
4. Reef-A-Palooza (a Southern California Marine Aquarium Society event), October 11-12
5. Second Annual Oklahoma City Conference for Reef Aquarists and Saltwater Enthusiasts (CRASE), October 25
6. Marine Aquarium Expo, April 3-5, 2009

MACNA XX, September 5 - 7

Date: Friday, September 5 through Sunday, September 7, 2008
Location: The Westin Peachtree Plaza, 210 Peachtree Street, Atlanta, Georgia 30303
Website: http://www.macnaxx.com

Presented by Atlanta Reef Club and MASNA, MACNA is the largest hobbyist marine conference in North America. New aquarium products, vendors will often wait until MACNA to release new products into the hobby. Hobby professionals, you will have a chance to meet and mingle with professionals in the hobby like Eric Borneman and Anthony Calfo. A chance to be at a conference with hundreds of other people just as obsessed with aquariums as you are.

We have selected the Westin Peachtree Plaza as the host hotel for this event. It is the tallest hotel in the western hemisphere. Our negotiated room rate is $119.00 per night with discounted parking. Everyone that stays in the hotel will be given free internet access from their rooms.

This 73-story tower, topped by the revolving Sun Dial Restaurant, Bar & View, graces the heart of Atlanta. Connected to AmericasMart, The Westin Peachtree Plaza, is steps from CNN, Georgia Aquarium, Georgia World Congress Center and the Georgia Dome.

Contact Information:

MACNA XX
1266 West Paces Ferry Rd.
Suite 194
Atlanta, GA 30327
PHONE:
FAX: 860.540.2351
E-mail: info@macnaxx.com
Contact Form

West Tennessee Frag Swap and Aquarium Show, September 27

When: Saturday, September 27, 10 AM - 4 PM
Where: 5719 Quince Rd, Memphis, TN 38119 (map)
Phone: 901-359-2199
Website: http://www.wtmrac.org/newfragswap.htm

Come learn more about the marine reef and aquarium hobby. Admission is $3/person. Coral frags for sale or trade. Great raffle prizes! Frag Demo. Table space available for $15 (reserve in advance).

For more information, either call 901-359-2199 or email klug3@comcast.net.

Southern Colorado Marine Aquarist Society Frag Swap, October 4

Date: Saturday, October 4th, 2008
Location: Crowne Plaza Hotel, 2886 South Circle Drive, Colorado Springs, CO 80906 (map)
Website: http://www.scmasfragstock.com/

The SCMAS FragStock will take place on October 4th 2008 at the Crowne Plaza Hotel in Colorado Springs Colorado. This event will feature Marine Livestock (no Fish) and Dry Goods vendors from Colorado as well as national vendors from around the country. The event will take place in the Salon A Grand Ballroom and feature raffle items and amazing corals. Check back frequently as vendors are added to the list. We will also be listing the Raffle items on this site as well. Below is the event layout (subject to change) and some

pictures of the Hotel. For more information or if you would like to be a vendor please send an email to Ldogg@thescmas.com.

Reef-A-Palooza (a Southern California Marine Aquarium Society event), October 11-12

When: October 11-12
Website: http://www.reefapalooza.org/index.html

Reef-A-Palooza (RAP) is an annual event promoted by the Southern California Marine Aquarium Society (SCMAS). Now in its fourth year, RAP can best be described as an indoor marketplace where sellers, exhibitors, and hobbyists of all types can buy, sell, trade, showcase their products to the marine hobbyist community. The main purpose of Reef-A-Palooza is to provide an enjoyable, positive atmosphere that is conducive to education and trade of both product and knowledge. As such, participating vendors range from large manufacturers, to retailers, to small livestock sellers, and participating hobbyists range from the beginner to the elite, rare-species coral farmer. It is the perfect venue to showcase new products in the marine aquarium industry as well as retail products for sale. We strive to rally a diverse range of participants into the one-day event so as to present the best value and interest to everyone involved. Considering our current bookings and the popularity of previous years, we expect 60+ vendors/exhibitors and well over 1,000 attendees this year!

Reef-A-Palooza provides the perfect venue for marine aquarium hobbyists to meet fellow enthusiasts, exchange information, and trade, and learn about new products. One of our main goals at Reef-A-Palooza, and within SCMAS, is to educate and enlighten the public with the latest knowledge in marine animal husbandry skills and environmental responsibility. For instance, SCMAS fully encourages the rapid advancement and allure of coral propagation as a viable alternative to wild harvest collection practices. As such, many of our booth vendors are local hobbyists who grow their own corals specifically to sell and trade at Reef-A-Palooza and similar events. SCMAS thoroughly encourages this type of "green commerce" for both the betterment and future of our hobby, as well as the resulting benefit to the marine environment.

Reef-A-Palooza is focused mainly to cater to the vendor and hobbyist, rather than as an educational conference. As such, we tend to attract customers who come specifically for the purpose of buying and seeing all the different exhibitor's booths and displays. Nonetheless, speakers, raffle drawings, and other entertainment are provided to help keep people around for most of the day, even after seeing all the booths. In addition, our promotional and marketing efforts are nearly guaranteed to attract high participation and attendance rates, and hence, heavy foot-traffic throughout the building. RAP 2007 is going to be HUGE this year due to the popularity of its new venue (Orange County Fair & Exposition Center, Building #14) as well as the number of sellers, vendors, and manufacturers involved. We now have 18,000 square feet of indoor, climate-controlled space in which to make this event a resounding success. Now into its fourth year, Reef-A-Palooza has quickly gained the reputation as an event that is NOT to be missed!

Second Annual Oklahoma City Conference for Reef Aquarists and Saltwater Enthusiasts (CRASE), October 25

When: October 25, 2008, 10 AM to 6 PM
Where: University Central Oklahoma Conference Center
Admission: Adult tickets are $15 each for general admission, $25 with prepaid gourmet box lunch. Children are $10 each for general admission, $20 with prepaid gourmet box lunch.
Website: http://www.mycomas.com/content/view/89/102/

After the fabulous success of CRASE 2007, Aquariums Tropical Fish Supply and the Central Oklahoma Marine Aquarium Society are pleased to announce the second annual Oklahoma City Conference for Reef Aquarists and Saltwater Enthusiasts (CRASE). This will be a single day event and will comprise keynote lectures by distinguished speakers in the area of saltwater aquariums. In addition, the President of COMAS, Dr. Paul Whitby, will be discussing aquascaping. There will also be a hobbyist frag sale, vendor and trade displays as well as numerous door prizes.

The list of prizes is beginning to take shape, please remember to stop by and check as it grows. For now, here are a few of the door prizes we will have:

- Gift Certificates to Aquarium Oddballs
- Gift Certificates to Aquariums Tropical Fish Supply
- Gift Certificates to Zoanuts
- And the Grand Prize this year is: A complete 75gallon Reefready system. This comprises a 75g All Glass mega flow tank (Donated by Aquariums) a custom built Oak Stand and Canopy, 2 4 foot T5 lights, return pump, plumbing for the overflows and a sump. The stand and canopy are not stained so that you can match the system to your house decor. This prize is worth over $1,500.

Guest speakers will be:

- Dr. Ron Shimek: Firstly, it is with great pleasure that the organizers of CRASE wish to announce that --after a great deal of requests from COMAS members---Dr. Ron Shimek will be returning to CRASE. Dr. Shimek will be discussing invertebrates used as clean up crews, commonly available and some not so commonly available. His talk will encompass the pros- the cons- the dos and the don'ts.
- Adam Mangino: The second presenter is a new face to the CRASE. Adam Mangino is one of the ORA team and is primarily involved with their captive breeding program and in particular he is responsible for the hybridization to create the indigo dotty-back. He will be talking on captive breeding of marine ornamentals.

- Dr. Sanjay Joshi: Also new to the CRASE is one of the most respected names in reef tank lighting. Dr. Sanjay Joshi has published numerous articles on spectral qualities of bulbs and the effect of various reflectors. It is fair to say the level of expertise he will be bringing to the CRASE is outstanding and I very much look forward to meting him. Dr. Joshi will be discussing various options in reef lighting with particular respect to both T5 and MH technology.

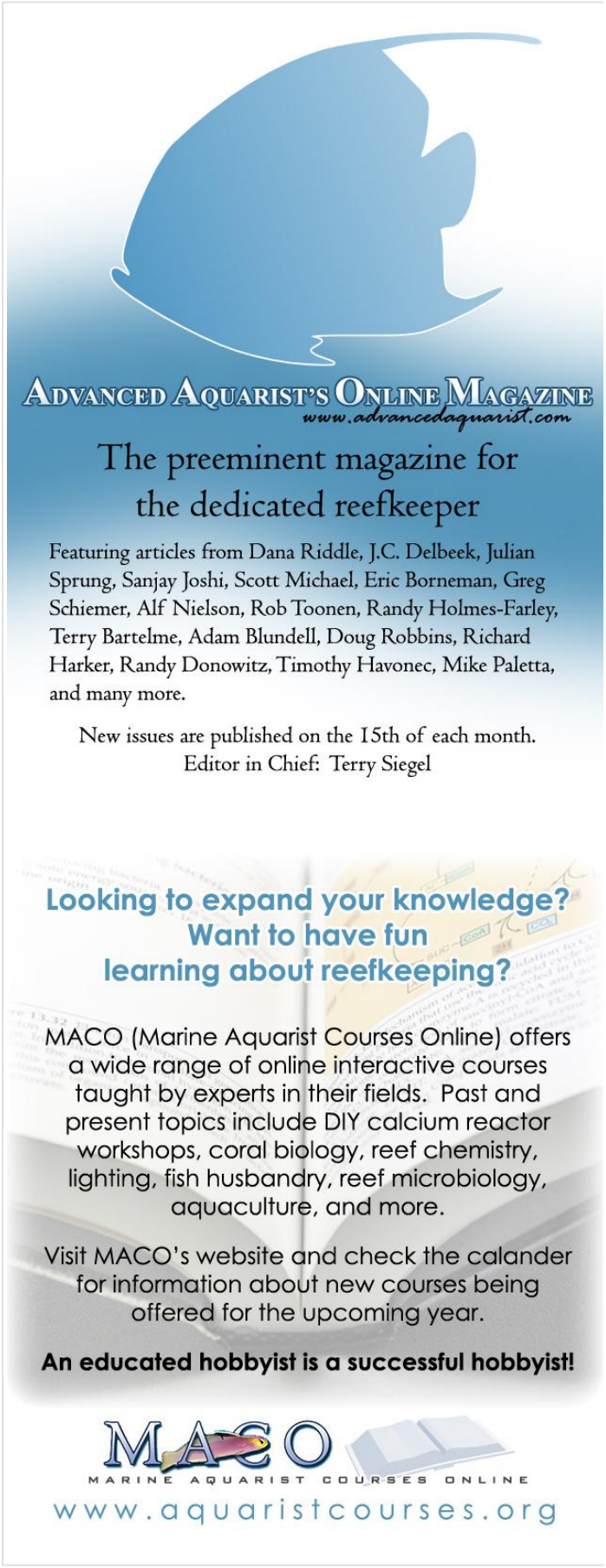
- Dr. Paul W. Whitby: Dr. Whitby is President of the Central Oklahoma Marine Aquarium Society (COMAS) and has over 20 years experience as a saltwater hobbyist. Dr. Whitby will be discussing aquascaping techniques.

Marine Aquarium Expo, April 3-5, 2009

When: Friday, April 3 - Sunday, April 5; 12:00 PM - 6:00 PM
Where: OC Fair & Event Center, 88 Fair Drive, Costa Mesa, CA 92626 (map)
Phone: 714-708-1500
Admission: $10 for Adults, $5 for Seniors, and FREE for Children 12 and under
Website: http://marineaquariumexpo.com/

Marine Aquarium Expo" (MAX), is southern California's premier indoor consumer-tradeshow, bringing together manufacturers, retailers, and saltwater enthusiasts from all over the nation into one giant, centralized location. More than 100 booths fill 22,000 square feet of exhibitor floor space plus another 7,000 sq. ft. of covered courtyard to accommodate speakers, raffle drawings, Club booths, and various workshops. MAX is the perfect venue to see the latest innovative products and offerings as well as the most progressive enterprises in the marine aquarium business. MAX is a spectacular marketplace for selling/trading of livestock, equipment, supplies, and various other goods. Literally THOUSANDS of coral frags are available for sale from the dozens of livestock exhibitors attending Marine Aquarium Expo. We invite you to bring the entire family to see what the excitement is all about. MAX is an event that you do NOT want to miss!

- Two Full Days of festivities, trade, and entertainment! Do not miss this event!
- Giant Market of Manufacturers, Wholesalers, Retailers, Hobbyists and more!
- Livestock Dealers selling corals, frags, fish, invertebrates, and more
- Courtyard classes provides a wealth of entertainment and learning experiences
- Many booths, workshops, and educational displays represented by clubs and charities
- Huge Drawing both days with many, many, Major Prizes to WIN!
- Manufacturers showcasing the latest equipment, products and services available!
- Six Speakers from all over the United States come to demonstrate, educate, and inspire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LATERAL LINES

BLUNDELL BUTTONS, PART I: THE PAST

By Adam Blundell M.S.

The overall goal was to show the potential for captive aquaculture.

Published August 2008, Advanced Aquarist's Online Magazine.

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Keywords (AdvancedAquarist.com Search Enabled): Adam Blundell M.S., Coral, Lateral Lines, Propagation, aquaculture
Link to original article: http://www.advancedaquarist.com/2008/8/lines

It has been a decade since my work with the propagation and study of a drab looking unknown bore of a coral. From what started as an interesting idea is now a full blown fairytale known as the Blundell Buttons.

BACKGROUND

As a young scientist I had a fascination with the marine ornamental hobby, and its role in the industry. I proposed a project one day to my fellow researchers and advisors. The plan was to track and document the collection, importation, and husbandry, and culture of a specific coral. We thought it could be an early attempt (if not the first) to track the coral over time. The overall goal was to show the potential for captive aquaculture.

SELECTING THE CORAL

This project was going to take years. We needed a coral we could follow and track. Therefore a set of requirements were developed for selecting the coral

1. it had to be something we could identify (differentiate from other corals)
2. it had to be something we could track

This colony is from the original Blundell collection, now housed in the Author's aquarium

That was about it. We found what seemed to be a perfect fit. We found a coral that was easily identifiable, rarely if ever seen in the hobby (at least in our location), easy to propagate, and not something we would expect to see in large numbers down the road.

WHAT IS THE CORAL

Well we didn't know for sure. At the time there was debate over the classification of the coral. The common identification book at the time was *Reef Coral* Identification by Humann (Humann 1993). This book did not list the coral, and rightfully so as the scientific community often sees corals as only being scleratinians, corals building skeletons. Humann did have this coral listed in his invertebrate book *Reef Creature Identification* (Humann 1992) and listed the coral as Palythoa grandis. Shortly following the onset of our project Julian Sprung wrote his wonderful book *Corals a Quick Reference Guide* (Sprung 1999). However, this book did not include the coral in question. A couple years later Eric Borneman wrote his masterpiece *Corals* (Borneman 2001) and this book listed the coral as Protopalythoa grandis. I asked Eric about this in person a few years ago and his answer was something like 'I'm still not sure if that is correct' (Blundell 2006). With such debate still taking place you can see how difficult it would have been to identify this coral years ago.

THE NAME

With a current debate on the naming of such coral in place, the University I was attending had trouble acquiring the export/import/

Shown here is the location of the original collection site.

collection permits. The original paperwork came back to me and have approval for this unknown coral which the government had labeled as "Blundell Polyps" on some forms and as "Palythoa Blundell" on another. I guess it was easiest for them to just put my name on the permit with the coral since I would be the person clearing them through customs (both away and US). Little did I know what role that would play in later years. For several months these were termed Blundell coral or Blundell Polyps and the like until a hobbyist named Steve Lopez stated that he was calling them Blundell Buttons. And so the name was given.

Initiating The Project

So the project began. We had our coral and we were ready to use it. We were going to propagate this coral and track it through the hobby. Here is how we did it.

1. I started with this coral and fragged off a couple of polyps. These polyps were then given away free to active members in my local aquarium club (Wasatch Marine Aquarium Society).
2. I gave explicit instructions to each person receiving polyps that stated that these corals were to never be sold. They were to be grown, fragged, and shared with others.
3. The new keepers were told that these corals were to be shared only with advanced aquarists who had the best chance of keeping the chain going. These second generation, third generation, forth generation, etc. owners were to continue the chain of producing free corals to expert reef keepers. A sort of pass it along free type of project to ensure survival.
4. The new keepers of these corals were to explain to the next person (and so on down the chain) that these corals were to be grown as part of a project to document how well or how poorly corals are aquacultured and distributed. Therefore we wanted everyone to track where the cultured polyps were going from owner to owner down the line.

I then took the original colony and held it in my hand. I had to decide what to do with this ever important rock. I knew I couldn't keep it. I can't imagine how bad I'd feel if it died in my care. So I thought of all the tanks out there, and all the great reef systems. I tried to think of the best possible aquarium. I thought of where this coral would have the best chance of surviving for all time and eternity. And that is where I put the coral.

Conclusion

That was the plan. Now, how well did it work? The results will be in the next article.

Author Information

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Here the laboratory aquarium is shown where the coral was held prior to being propagated.

ONLINE COURSES

AQUARIUM PHOTOGRAPHY

By D. Wade Lehmann

Marine Aquarist Courses Online (MACO) is proud to offer, starting this fall, a two-stage course for aquarium photography.

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Keywords (AdvancedAquarist.com Search Enabled): Chemistry, D. Wade Lehmann, Fish, Online Courses, Photography, Husbandry
Link to original article: http://www.advancedaquarist.com/2008/8/maco

MACO will host the return of Fish Husbandry and Reef Chemistry courses as well as a brand new course on aquarium photography! Please check the website for full details including dates and costs.

http://www.aquaristcourses.org

Direct links to each course:

- Aquarium Photography I
  http://www.aquaristcourses.org/aqphoto/
- Fish Husbandry
  http://www.aquaristcourses.org/Fish%20Husbandry2/
- Beginner's Reef Chemistry
  http://www.aquaristcourses.org/reefchem2/

AQUARIUM PHOTOGRAPHY TECHNIQUES

This course begins September 14, 2008, register now! For registration, please see the following link: http://www.aquaristcourses.org/aqphoto/Aquarium%20Photography%20Techniques%20-%20Registration.

LEVEL I

Through interactive online learning with practical, hands on photography assignments and critiques of your images through your own student gallery on the MACO website, you will gain a thorough understanding of how to capture stunning photographs of marine or freshwater aquariums and their aquatic inhabitants.

During the Aquarium Photography Techniques - Level I course, you will learn how to utilize your camera equipment (including electronic flash) to capture clear & compelling images of aquariums under different conditions as well as the basic rules of composition and fundamental macro photography techniques.

We will examine how to 'set the stage' in an aquarium for your photo shoot while discussing a variety of techniques for capturing images of a variety of subject matter, including corals, invertebrates, and (of course) fish. We will also cover methods of photographing entire aquarium environments.

The Aquarium Photography Techniques - Level I course will also include an introduction to multimedia uses for your images & methods for displaying and sharing them as well as basic post-production skills, including digital file management and computer manipulation.

LEVEL II

In Aquarium Photography - Level II, utilizing similar interactive, online learning methods, we expand on many of the photographic skills and techniques learned in Level I. We will also learn about the

use of some additional, specialized camera equipment and proceed to more specific and advanced techniques required to capture consistently stunning, or professional quality photographs of aquariums and their aquatic residents.

Throughout Level II, you will participate in additional hands-on photography assignments that will allow you to hone and practice your photography new skills. There will be regular critiques of your images through your own student gallery on the MACO website, which will help you to further improve your photography.

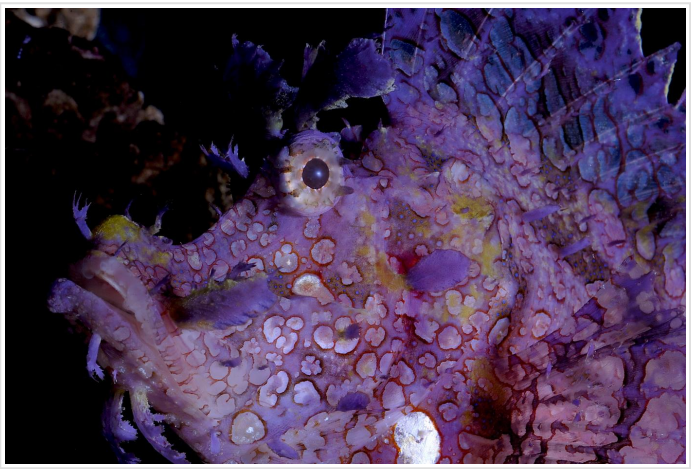
During Aquarium Photography Techniques - Level II, you will learn about…

- The use of specialized camera equipment and software for capturing unique, creative images of aquariums and their aquatic inhabitants
- Creating outstanding images through the effective use of visual design elements & imaginative composition
- Creative lighting techniques & specialized lighting equipment that will help you modify the quality of the light and improve your images
- More advanced digital Imaging techniques for enhancing your images and correcting problems you encounter while shooting
- Ways of successfully working with different & difficult subject matter & aquarium set-ups
- Ways you can use your photographs, including how to share and display them for your friends and also how to get your best images published and possibly make some money selling your photos (if you are so inclined)

MACO will also host the return of Fish Husbandry and Reef Chemistry courses! Please check the website for full details including dates and costs. www.aquaristcourses.org

Direct links to each course:

- Aquarium Photography I - http://www.aquaristcourses.org/aqphoto/



- Fish Husbandry - http://www.aquaristcourses.org/Fish%20Husbandry2/

Aquarium Photography Course - Syllabus

Week 1

Introduction

Camera Equipment

- Camera Bodies
- Lenses
- Macro Equipment
- Flash
- Tripods
- Filters

Computers for Photography

Week 2

Creative Use of Camera Controls

- Shutter Speed
- Aperture / f-Stop
- ISO
- Color balance

Digital Imaging 1

- File formats
- File Preparation
- Resolution
- Cropping / Resizing

Week 3

Light

- Reflections & their avoidance
- Lighting
- Electronic Flash

Aquarium Preparation

- Cleaning
- Aquascaping
- Photo-specific tanks

Week 4

Composition

Digital Imaging 2

- Color Correction
- Exposure & Contrast
- Sharpening & Blurring
- Rubber Stamp & Heal

Week 5

Aquatic Subject Matter

- Full Aquarium Photographs
- Aquatic Animal Portraits
- Macro & Close-ups

Introduction to Lighting Theory

Week 6

Uses and Things to Do With Your Photos

- Multimedia & Internet
- Printing

Wrap-up

Prerequisites

- Fundamental knowledge of basic photography
- Fundamental knowledge of computers & file management
- A basic knowledge of working with digital photos on your computer
- Thorough knowledge of the operation of your camera (familiarity with all buttons & modes)

Student Equipment

If you are thinking about purchasing new camera equipment in the near future, please consider postponing your purchases until after our first class, as we will be discussing what to look for in camera equipment.

Required Gear

- Camera body (Much of the course content will be geared toward participants shooting with digital SLR cameras. However, the majority of course content will also be relevant to users of [highly functional] point-and-shoot cameras and those shooting with film.)

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An immense reference library
A thriving real time IRC chat room
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A professional monthly online periodical
Advanced Aquarist's Online Magazine | www.advancedaquarist.com
A college-styled online curriculum
Marine Aquarist Courses Online | www.aquaristcourses.org
An interactive LFS finder
Aquarium Store Finder | www.aquariumstorefinder.org
Latest news about upcoming events, frag trading, special sales for Reefs.org members, professional wallpapers, polls, and much more!
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www.reefs.org
a global community of friendly, informed, and conscientious reef enthusiasts

- Lens (Most quality, standard lenses will work for this course) (having a variety of focal lengths available will be beneficial)
- Computer (to deal with digital images) (will need sound card and speakers / headphones)
- Photo editing software (class materials will be based on 'Photoshop Elements' but any good photo editing program will likely do)
- Access to an (functioning) aquarium to photograph during the course

Recommended Gear

- Tripod (highly recommended)
- Flash (highly recommended-more than one is helpful)
- Additional lenses (A range of lenses / focal lengths from wide to tele-photo)
- Macro lens
- Scanner (if you are shooting film for class) (or access to a photo-finishing lab that will scan film for you)

Fish Husbandry Course

MACO is also offering the popular Fish Husbandry (http://www.aquaristcourses.org/Fish%20Husbandry2/). Please see the website for registration and full course details, including syllabus and instructor bio.

This class will introduce you into the world of marine fish husbandry, from basic biology and taxonomy, to principles and procedures used to insure that these animals live out long and healthy lives under your care. You'll learn how to select the proper equipment, and be guided on how to set up your system in a way that suits the fish that you've chosen and the environment that you would like to emulate. Most importantly, you'll learn to avoid all the mistakes that are so easily made when learning to keep these amazing animals.

The class will cover the tendencies and idiosyncrasies of various families of marine fish, how they interact with each other, and how to keep them together without experiencing the problems that plague so many aquarists.

You'll learn how to manage and avoid diseases that commonly infect and often kill so many captive marine fish. You'll learn what you must do, and as importantly, what you must not do in order to excel as a marine fish keeper.

From a previous student of the course: "Thanks for the great class. I feel much more confident now than I did 6 weeks ago in my ability to develop a reef aquarium."

Reef Chemistry Course

MACO is also offering the popular Reef Chemistry (http://www.aquaristcourses.org/reefchem2/). Please see the website for registration and full course details, including syllabus and instructor bio.

There is a moderately steep learning curve associated with aquarium chemistry and hobbyists often get conflicting or confusing responses when they ask questions of their local aquarium/pet stores or other hobbyists. The main goal of this course is to dispel some of the confusion and mystery that surround subjects of marine aquarium chemistry. It will do so by providing the background necessary for understanding basic subjects such as the differences between atoms and ions as well as complex subjects such as ionic strength and the marine carbonate buffer system. It is the instructor's goal that, by the end of the course, students feel comfortable with both the science-specific end of aquarium chemistry and what it means in the real world. This course is a review, but it will have information for a range of aquarist experience from early beginners to more advanced individuals.

PRODUCT REVIEW

Maxi Jet Utility Pumps 1100, 1800 and 3000

By Jake Adams

The Maxi Jet line has finally been revamped to include more powerful models known as the Maxi Jet Utility (MJU) pumps.

Published August 2008, Advanced Aquarist's Online Magazine.

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Keywords (AdvancedAquarist.com Search Enabled): Jake Adams, Product Review, Pumps, MaxiJet
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For years the Maxi Jet line of pumps has been one of the most popular powerheads of the aquarium hobby. Originally designed for general circulation and powering undergravel filters, the pumps have been reapplied for powering skimmers, reactors, media filters and there are modification kits available which elegantly convert the centrifugal pumps into propeller pumps. The pumps' only drawback was that the largest model had a maximum flow rate just shy of 300 gallons per hour. Enter 2008 and the Maxi Jet line has finally been revamped to include more powerful models known as the Maxi Jet Utility (MJU) pumps. This review features the three largest currently available models, the MJU 1100, MJU 1800 and MJU 3000, although two larger models are scheduled to be released in the near future.

First Impressions

The packaging on the outside of the box is surprisingly useful. The front panel clearly states the model number, maximum flow rate and expected flow rate at four feet of head pressure. Although many pump manufacturers include some kind of flow curve for larger pumps, it is useful for hobbyist to know how a pump will perform at a typical height for flow return from a sump. The MJU pumps come with a 3-year warranty and I expect them to be dependable. Out of the box the pumps have a good feel when handled, the parts fit together tightly yet most of the adjustments and conversions can be performed without the use of tools. Just like the classic Maxi Jets, the MJU pumps come with a slew of parts and fittings to get the maximum functionality for a range of applications but the pumps have a two-prong, ungrounded plug. The parts include (temporarily useful) suction cups, male threaded barb fittings with an o-ring seal and the internal and external use faceplates.

Internal or External Use

One of the main changes which differentiate the Maxi Jet Utility line from the classic Maxi Jets is their ability to be converted from an internal powerhead or pump to an external pump simply by switching the faceplate. The faceplates of the MJU 1100 are snap on but the larger MJU 1800 and 3000 have two stainless steel screws which firmly fasten the internal use faceplate. All of the internal use faceplates have a flow adjustment "disc" which doubles as an intake screen. This built-in flow control is useful for quick adjustment of the flow rate but when used in a reef this disc will likely be difficult to adjust once it becomes bio-fouled by encrusting organisms if it is not frequently cleaned. Furthermore, all the MJU pumps have a female threaded outlet, ½" for the MJU 1100 and ¾" for the MJU 1800 and 3000, and the external use faceplates have female threaded inlets of the same size. The inlet and outlet threads can accept the included barbed adapter or they can be hard plumbed using standard PVC fittings.

Comparisons

The MJU 1100 seems identical to the beloved Maxi Jet 1200 in power draw and flow output. Both have a maximum flow rate of 294 GPH, a 21 watt power draw and have very similar shape and size. I suspect that both pumps use the same motor however they do use slightly different impellers. Interestingly, the impeller has switched from an internal bearing design where the magnet and impeller spin freely around a central shaft to an external bearing design where the magnet and impeller are fixed to the shaft with the bearings at either ends of the shaft. Presumably this design change yields an increase in efficiency. The MJU 1100 housing is more suited for switching

Maxi Jet Utility 3000 pump shown with the internal use faceplate, including the flow controlling intake screen and disc. Note the two screws used for removing this faceplate.

between internal or external use and the external use faceplate will accept the standard intake screen that comes with both the MJ 1200 and the MJU 1100. Additionally, unlike the MJU 1100, the MJ1200 cannot be (safely) hard plumbed with PVC fittings as it does not have a threaded inlet or outlet.

The MJU 1800 is rated for a maximum of 475 GPH and an expected 255 GPH at four feet of head pressure with a maximum power draw of 38 Watts. Both the flow rates and the power draw of the MJU 1800 are in between a Mag-Drive 3 and Mag-Drive 5 in values but the MJU 1800 is noticeably quieter than either Mag-Drive models. Furthermore, with all of the included components the MJU 1800 has more varied functionality than a Mag-Drive which only includes an intake strainer and pre-filter.

The Maxi Jet Utility 1100 pump is shown here with the internal use faceplate and the parts for conversion to external or inline use which can be changed over without tools.

A Maxi Jet 1200 is shown here next to the similar yet more versatile Maxi Jet Utilty 1100. Note the change in impeller design; the MJ1200 has an impeller with an internal bearing and the MJU 1100 impeller has an external bearing.

Finally, the MJU 3000 is rated for a maximum of 775 GPH and an expected flowrate of 500 GPH at four feet of head pressure with a maximum power draw of 58 Watts. The performance values of the MJU 3000 compare to a Mag-Drive 7 and an Eheim 1260, both of which have a power draw of 60 Watts and comparable pressured flow rates. Like the Eheim 1260 the MJU 3000 is virtually silent whereas the Mag-drive 7 is noticeably audible. Also, the MJU 3000 is about the same size as a Mag-drive 7 but it is noticeably smaller than the hunk of a pump which is the Eheim 1260.

Testing

Specifications obtained under carefully controlled testing conditions are useful for knowing how well equipment *can* perform but a new product has no street credentials until it is tested and used under real world conditions. The Maxi Jet Utility pumps were tested for flow rate and power consumption. Power draw was measured using the Kill-A-Watt as featured by Dana Riddle in last month's issue and

The Maxi Jet Utility 3000 is shown here sandwiched between some usual suspects, a Mag-drive 7 on the left and an Eheim 1260 on the right.

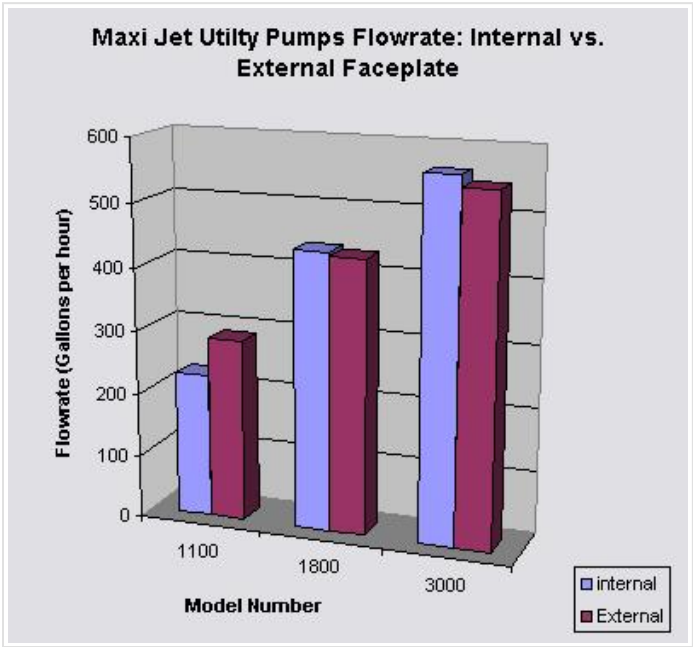

Figure 1

the flow rate was measured using a King Instruments rotameter (the rotameter adds 18 inches of pressure which was accounted for in these tests). One of the first things I wanted to test was how the MJU pumps would be affected by using either the internal or external faceplates. Figure 1 shows that there was a significant difference in performance for the MJU 1100 where it pumped about 40 gallons more per hour using the external use faceplate over the internal use faceplate. There was no significant difference in the flow rate of the MJU 1800 or MJU 3000 whether they used the internal or external use faceplates.

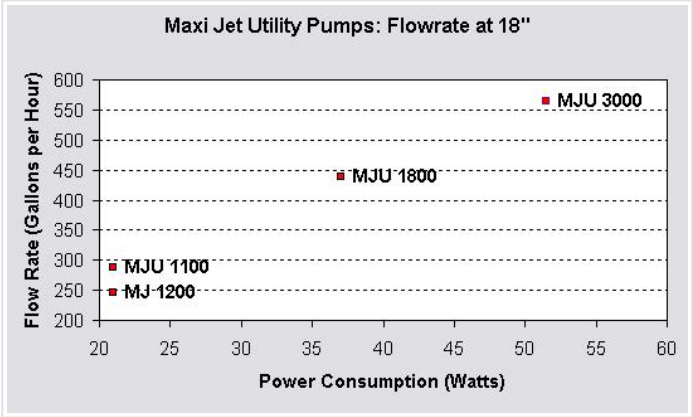

Figure 2

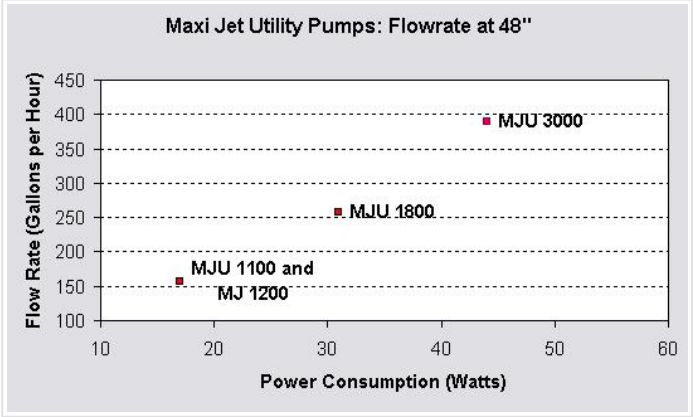

Figure 3

Next, the MJU pumps and an MJ 1200 were tested at 18" and 48" of head pressure. Figure two shows the results of testing at 18" and Figure 3 shows the results of testing at 48" of head pressure. I would have liked to test all the pumps with no head pressure but the rotameter precluded this. As you can see in figure 1, the MJ 1200 pumped slightly less volume than the MJU 1100 at 18" of head pressure but interestingly, at 48" of head pressure the MJ 1200 and MJ 1100 pumped the same volume of water while consuming the same amount of power. Otherwise, all the tests show results that are in line with the advertised flow rates and I assume that discrepancies are due to artifacts of how the tests were carried out. The last test I performed was to measure how much the MJ 1200 and MJU 1100 pumped through a classic AquaC Remora hang-on protein skimmer. This test was performed by repeatedly timing the fill rate of a known volume and taking the average. Once again there was a negligible difference in output with the MJU 1100 pumping 92 gallons per hour through the Remora and the MJ 1200 pumping 88 gallons per hour.

Conclusion

Since the end of the metric tests I have had all three pumps in use for a range of applications. The MJU 1100 is powering an AquaC Remora while producing a similar output of skimmate as I would expect from the MJ 1200 I previously used. The MJU 1800 is providing return from a sump for a 110 gallon fish tank and the MJU 3000 is currently driving a small tiered propagation system with outputs at 4 feet and 6 feet from the sump. I am getting a reasonable flow rate from both pumps and I am especially pleased with how quiet they are. Although there is no manufacturer suggested retail price, the pumps will likely retail at $50-60 for the MJU 1100, $70-80 for the MJU 1800 and $120-130 for the MJU 3000. The pumps are not breaking any ground in terms of performance or efficiency, but with the Maxi-Jet reputation and a 3 year warranty I find great value in the Maxi Jet Utility line's versatility and even more value in their quietness.

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HelloLights has been in business since 1997 providing the aquarium industry with high quality lighting products and accessories. Throughout the years, our mission has been to be the aquarium hobbyist? one stop source for all of their lighting needs. With unsurpassed customer service and high quality products, we truly believe we are the clear choice for aquarium lighting. We realize that lighting is one of the major purchases that the hobbyist will make when setting up an aquarium, and we take great pride in our role in this process.

Marine Depot

MarineDepot.com is the current leader in supplying marine and reef aquarium supplies. We simply try to make as many people (including both our staff and our customers) as happy as possible. We found that we have been able to accomplish this by maintaining extremely low prices, providing friendly customer service, and simply liking what we do.

Premium Aquatics

Premium Aquatics is a family owned and operated aquarium business. We have been in business since April 1996 and we are dedicated to serving the aquarium hobbyist. Our mission is to bring you the highest quality aquarium products and livestock available and at a reasonable price and to provide honest non-bias information on all of our products and our competitors. Our goal is customer satisfaction, we want your return business.

Salty Supply

Our goal is to provide only the best aquarium supplies available and to promote successful and responsible husbandry for all of our aquarium animals. We stock hundreds of the best aquarium and reef supplies and constantly growing. Some of which include, protein skimmers, chillers, calcium reactors, reverse osmosis systems and replacement filters and we specialize in reef tank lighting. We are adding to our inventory daily so be sure to visit us often.

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The Two Part Solution is a method of adding calcium, alkalinity and magnesium to your reef aquarium. What's unique about this solution is many of the items used are household items or just bulk supplies of the very same products you are buying two cups of for $20 just because it has a fancy package. It has been time tested by thousands of aquarists and proven to not only be incredibly effective and easy to use but also extremely affordable. There is simply no other balanced calcium, alkalinity and magnesium solution out there that is so ridiculously cheap and has no expensive and intimidating equipment to buy.

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Quality Aquarium supplies, equipment, and livestock at reasonable prices. J&L Aquatics was formed in December 1997. Our business was started from our love of the aquarium hobby. We at J&L Aquatics felt that the Canadian aquarist should have the option to purchase top quality supplies, equipment and livestock other than the generally over priced local retail stores. With this philosophy in mind we have successfully operated and grown our business for the past five years.

Marine Garden

We started almost a decade ago on a small place in south Florida now, over the years Marine Garden not only have grown but had developed new techniques on keeping corals and Fishes as healthiest as if they were on the Ocean. Most of our corals are 100% captive grown by ourselves or other Professional hobbyists. By purchasing aqua cultured corals, since they use to be in captivity you are getting not only the best quality but also a stronger and harder specimen. Also, you will be helping to minimize the problem of the declining coral reefs in our oceans

Reef Nutrition

Reef Nutrition Marine Live Feeds are produced by Reed Mariculture, the world's largest producer of marine microalgae concentrates. We supply algal feeds and zooplankton to universities, marine ornamental growers, and over 500 fish, shrimp, and shellfish hatcheries in 70+ countries around the world.

Southern California Caulerpa Action Team

An important goal of the Southern California Caulerpa Action Team is the detection of undiscovered infestations of C. taxifolia or other invasive species of Caulerpa, and the prevention of their spread.

Sunlight Supply, Inc.

Sunlight Supply Inc. is a manufacturer and importer of High Intensity Discharge (H.I.D.) and fluorescent lighting fixtures. We specialize in fixtures with applications in the hobby & commercial horticulture and reef tank aquarium industries. Sunlight Supply Inc. is a recognized and respected leading brand in the marketplace.

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